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Impact d'une suralimentation prolongée et d'une supplémentation en polyphénols sur le profil d'activité physique et de sédentarité

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Résumé

La surnutrition est une méthode classique pour investiguer les mécanismes de régulation de la masse corporelle chez l'humain. Le concept qu'une surnutrition pourrait produire des changements de la dépense énergétique, de la sédentarité et du profil d'activité physique ayant un rôle important sur la balance énergétique a été le sujet de nombreuses études, mais il demeure incomplet. Par exemple, aucune étude de surnutrition à ce jour n'a mesuré à la fois la sédentarité et le profil d'activité physique. Ce projet comprend donc une approche globale où dix-sept paramètres de sédentarité et d'activité physique ont été mesurés avant et après une suralimentation de 31 jours à 150% de la dépense énergétique journalière. La diète était constituée de collations riches en lipides et en glucides. Les sujets étaient évalués dans un contexte de vie réelle à l'aide d'accéléromètres. Une autre avancée concernant le projet de ce mémoire est l'utilisation d'une supplémentation en polyphénols (procyanidine, anthocyane et resvératrol) de 2g par jour obtenue à partir de raisins rouges pour vérifier si elle peut protéger des effets délétères de la suralimentation en analysant comment elle peut affecter le profil d'activité physique. Alors que le temps passé à courir et la dépense énergétique de repos ont augmenté de 49.0% dans le groupe placébo et 49.1% dans le groupe polyphénols et de 2.3% dans le groupe placébo et 2.2% dans le groupe polyphénols, respectivement, au cours du protocole de suralimentation, il n'y a pas eu d'interaction entre la supplémentation en polyphénols et la suralimentation sur les paramètres de sédentarité et d'activité physique. Il est intéressant de noter que l'indice de mesure de l'activité physique non structurée, associé dans la littérature scientifique au piétinement, à la station debout et à la marche, diminue en cours de suralimentation, suggérant des changements adaptatifs plus subtils au niveau de l'activité physique, tels que remuer, la contraction musculaire spontanée et le maintien de la posture. Cette observation doit toutefois être validée par des études futures. Mis-à-part ceci, peu de changements ont été observés suite à une consommation en polyphénols et une surnutrition.

Mots-clés : suralimentation, polyphénols, activité physique, dépense énergétique, sédentarité, accéléromètre, collations, environnement obésogène

Abstract

Overfeeding has been a classical technique for investigating the mechanisms of body weight regulation in humans. The concept that changes in energy expenditure, sedentary time and physical activity parameters may play an important role in the regulation of energy balance has been the subject of many investigations, but our understanding remained incomplete. For example, no overfeeding study to date has measured both sedentary and physical activity profiles. This research project thus includes a global approach where seventeen sedentary and physical activity parameters were assessed before and following 31 days of overfeeding at 150% of daily energy expenditure. The diet consisted in snacks rich in fat and sucrose. Subjects were assessed in a free-living condition using accelerometers. Another novelty of this work is that we investigated if the use of 2g/day of a polyphenol supplementation (procyanidin, anthocyanin and resveratrol) obtained from red grapes can protect from overfeeding and how activity profile can be impacted by this supplementation. While time spent running and resting energy expenditure increased by 49.0% in the placebo group and 49.1% in the polyphenols group and 2.3% in the placebo group and 2.2% in the polyphenols group respectively over the course of the overfeeding protocol, there was no interraction of polyphenol supplementation and overfeeding on sedentary and physical activity parameters. Interestingly, the non-exercise activity thermogenesis index, linked to trampling, standing and walking decrease with overfeeding, suggesting adaptive changes in more subtle elements of none-volitional physical activities, such as fidgeting, spontaneous muscle contraction and maintaining posture when not recumbent. This observation must however be validated by a future investigation. Aside from these findings, few changes have been observed following polyphenol consumption and overfeeding.

Keywords : overfeeding, polyphenols, physical activity, energy expenditure, sedentariness, accelerometry, snacking, obesogenic environment

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CRP : protéine C-réactive

DIT : diet-induced thermogenesis

HMB : Beta-hydroxy-beta-méthylbutyrate

IMC : indice de masse corporelle

Il-6 : interleukine 6

NEAT : non-exercise activity themogenesis (activité physique non structurée)

TNF-α : facteur de nécrose tumorale alpha

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Introduction

La problématique de la prise de masse corporelle

Il fut un temps où la prise de masse corporelle était un signe de santé et de prospérité en occident (Vigarello, 2013). De nos jours, des aspects sociaux et culturels reliés à la prise de masse corporelle demeurent (Paeratakul, 2002; Nolin, 2007; Sobal, 2017). Par exemple, un mouvement d'acceptation du gras est apparu en Amérique du Nord au cours de la dernière décennie, remplaçant l'image de beauté qui était jusqu'alors associée uniquement à la minceur (Afful, 2015). Un individu gagnant de la masse grasse peut donc aussi bien rejoindre les attentes de sa société et/ou de sa culture qu'il peut s'en éloigner. Toutefois, ces étiquettes ne considèrent pas nécessairement la nature pernicieuse de la prise de masse corporelle. En effet, la prise de masse corporelle à elle-seule peut entrainer des conséquences notables sur la santé. Des augmentations mesurées dans le cadre d'études longitudinales sont associées à des changements nuisibles pour plusieurs paramètres cardiovasculaires et métaboliques, y compris la pression artérielle, la dyslipidémie, les marqueurs de l'inflammation systémique et la résistance à l'insuline (Alley and Chang, 2010 ; Berrahmoune et al. 2008 ; Chan et al. 1994 ; Fransson et al. 2010). Par exemple, un gain de masse corporelle entre 2.5 kg et 10 kg du début jusqu'à la moitié de l'âge adulte augmente l'incidence de risque relatif de 1.75 pour le diabète de type 2, de 1.13 pour les maladies cardiovasculaires et de 1.26 pour les cancers reliés à l'obésité et l'hypertension (Zheng, 2017).

La prise de masse corporelle peut éventuellement mener à l'obésité, qui est définie comme étant « une accumulation anormale ou excessive de graisse corporelle qui représente un risque pour la santé » (OMS, 2018). Le statut d'obésité, mesuré via l'indice de masse corporelle (IMC) qui correspond au poids de la personne (en kilogrammes) divisé par le carré de sa taille (en mètres), représente un résultat de 30 kg/m^2 ou plus. Selon l'Organisation mondiale de la santé (2017), une majorité de la population mondiale vit dans des pays où le surpoids (IMC égal ou supérieur à 25 kg/m^2) et l'obésité font davantage de morts que l'insuffisance pondérale. Au Canada, l'obésité contribue directement entre 61% et 74% au cas de diabète de type 2, entre 17% et 32% aux cas d'ostéoarthrite, entre 14% et 21% aux cas de cancers colorectoraux, entre 8% et 14% aux cas de dépression et à 20% des cas de morts prématurées (Jansen et al. 2013). Une étude effectuée au niveau de la population européenne a établi que l'obésité à elle-seule contribue aux cardiopathies ischémiques à 35% et à l'hypertension à 55% (Brandt and Erixon, 2013). Ces résultats sont alarmants, d'autant plus que des données de 2008 basées sur des mesures directes de l'indice de masse corporelle révèle que 25,5% de la population canadienne adulte est obèse (Corscadden et al., 2011). Il s'agit de la dernière étude à ce jour utilisant des mesures directes chez une population canadienne, mais ce pourcentage ne semblerait pas en voie de diminuer selon une étude épidémiologique mondiale rassemblant des données de 1990 à 2015 (GBD Obesity Collaborators, 2017).

La prise de masse corporelle menant à l'obésité implique des dépenses économiques énormes pour la société. En effet, ses répercussions sur le plan de la santé s'accompagnent par des coûts monétaires élevés. En 2006, les coûts directs de santé au Canada étaient de 3,9 milliards dollars (hospitalisation, médicaments, médecins, service d'urgences) et de 3,2 milliards dollars en coûts indirects (coûts reliés à l'invalidité et à la diminution de la productivité causée par la maladie ou la mort prématurée) (Jansen et al. 2013). En 2012, le coût total annuel attribué à l'obésité était de 200 milliards de dollars américain aux États-Unis et de 81 milliards d'euros annuellement en Europe (Cawley and Meyerhoefer, 2012; Hunt and Ferguson, 2014).

Enfin, la prise de masse corporelle est progressive et l'obésité se développe chez l'individu sur une période de temps pouvant aller de quelques mois jusqu'à plusieurs dizaines d'années et ce, autant de la naissance à la pré-adolescence (Agras, 2002), de l'adolescence à l'âge adulte (Kimm, 2002) et chez l'adulte (McTigue, 2002). Une fois le poids gagné, il est difficile à perdre et cela semble encore plus véridique lorsque la prise de poids s'est installée sur plusieurs années (Le Petit, 2006). Outre les études d'interventions en perte de masse corporelle, la compréhension du développement de l'obésité ainsi que le renversement de ses effets néfastes suscitent un intérêt marqué et ce, dans l'espoir d'agir également sur un plan préventif.

Les causes de la prise de poids menant à l'obésité

L'épidémiologie de l'obésité chez l'adulte permet de constater que les taux d'obésité étaient relativement stables avant les années quatre-vingt (Hu, 2008). Des augmentations considérables ont par la suite été observées, entre autre en Europe (Seidell, 1995) et aux États-Unis (Ogden, 2010). Selon l'Organisation mondiale de la santé (2017), le nombre de cas d'obésité a presque triplé mondialement depuis 1975, de sorte que 650 millions adultes étaient obèses en 2016, représentant 13% de la population mondiale âgée de 18 ans et plus. Au Canada, la prévalence de l'obésité a également triplé de 1985 à 2011, passant de 6,1 à 18,3% (Twells, 2014). Les facteurs hérités influenceraient jusqu'à 70% de la tendance à développer l'obésité (Stunkard, 1990). Toutefois, la génétique à elle-seule ne peut pas expliquer ces augmentations notables à partir des années quatre-vingt. Sachant que l'expression de ces facteurs hérités est en partie déterminée par l'environnement et les habitudes de vie, le développement de l'obésité est en partie sous contrôle volontaire. Tel que décrit à la Figure 1, la prise de masse corporelle considère un ensemble de facteurs qui se traduit par une balance énergétique dynamique.

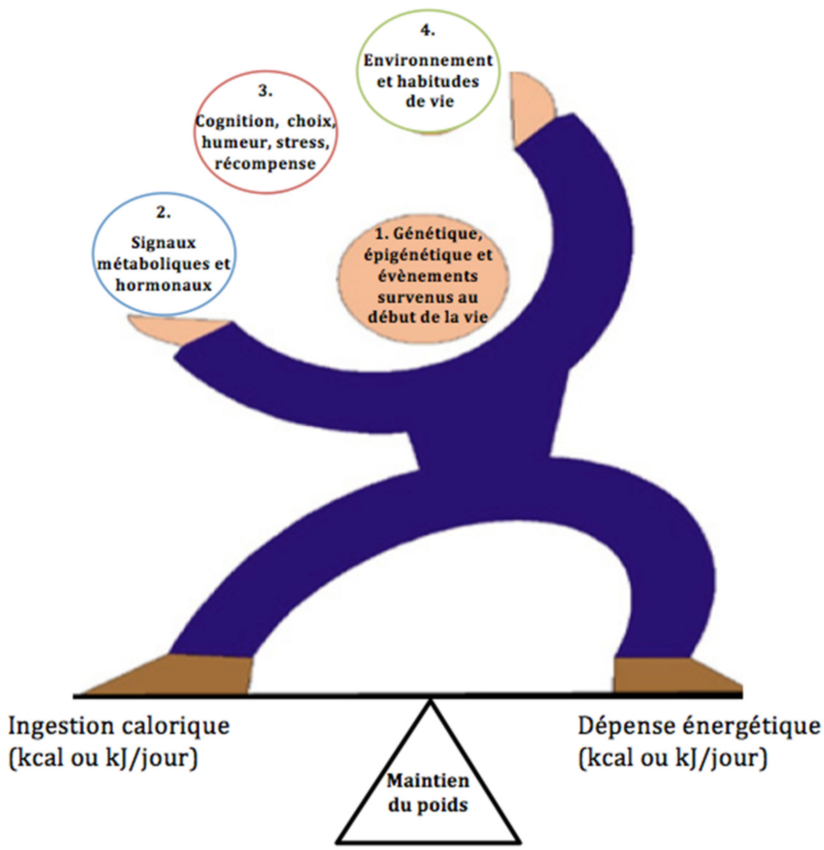

Figure 1. *Facteurs influençant l'ingestion calorique et la dépense énergétique.* Adaptation à partir de Manore, 2017

À travers ce concept proposé par Manore (2017), il existe une nuance intéressante dans le fait que la balance énergétique considère l'ingestion calorique et la dépense énergétique comme étant interreliées, complémentaires et synergiques. Les fluctuations du poids corporel sont ainsi influencées à la fois par la génétique, les signaux métaboliques et hormonaux, les éléments biopsychosociaux, l'environnement et les habitudes de vie. Sur cette lancée, plusieurs déterminants ont été établis comme causes potentielles. Des méta-analyses ont fait ressortir que la prise de masse corporelle est influencée positivement par une augmentation des calories ingérées (Rosenheck, 2008), la composition et la proportion des aliments ingérés (Romieu, 2017), le fait de grignoter (Nederkoorn, 2010) et le manque de sommeil (Cappucio, 2008). D'autres méta-analyses supportent aussi l'influence de facteurs plus ou moins contrôlables tels que le stress (Wardle, 2011), le statut économique (Evans, 2000; Newton, 2017) et un dérèglement hormonal et métabolique (Choi, 2013; Thota, 2017).

L'obésité est pour ainsi dire de nature multifactorielle. L'approche et la compréhension des études expérimentales évaluant les phases de la prise de poids doivent donc tenir compte de ce phénomène. Comme il sera possible de le constater dans les prochaines sections, l'étude principale de ce mémoire considère cette balance dynamique en mesurant de manière détaillée plusieurs paramètres d'activité physique et de sédentarité, tout en considérant leurs interactions avec une supplémentation nutritionnelle.

Le renversement de la prise de masse corporelle et de l'obésité

La prise de masse corporelle est associée à des complications pour la santé. Toutefois, existe-il des moyens de réduire ses effets délétères malgré un environnement obésogène? Swinburn et al. (2004) rapportent l'existence de plusieurs facteurs de protection contre l'obésité : une pratique d'activité physique régulière et une haute consommation de fibres comme étant statistiquement les plus convaincants. Outre la consommation de fibres, la présence d'antioxydants aurait possiblement un rôle notable sur le renversement de la prise de masse corporelle. Les polyphénols, une classe de composés phytochimiques naturels, s'avèrent être des modulateurs de voies physiologiques et moléculaires impliquées dans le métabolisme énergétique, l'adiposité et l'obésité (Meydani, 2010). Au cours des deux dernières décennies, la communauté scientifique s'est intéressée à son rôle dans le maintien de la santé. Une revue systématique de la littérature réalisée en 2017 par Fahrat *et al.* conclut que les polyphénols pourraient prévenir des augmentations de la masse corporelle en condition de surnutrition, mais que d'autres études sont nécessaires afin d'affirmer qu'une supplémentation en polyphénols pourrait être une approche complémentaire aux interventions de régulation de la masse corporelle. Le rôle physiologique des polyphénols a été exploré par plusieurs. Des évidences existent concernant l'augmentation du métabolisme des lipides suivant la consommation de polyphénols (Vaughan, 2013; Mele, 2017). Cette consommation riche en polyphénols serait également suivie d'une augmentation de la dépense énergétique (Mahendra, 2017), via l'augmentation de la dépense énergétique de repos (Most, 2014; Dulloo, 1999) et la themogénèse alimentaire (Shixian, 2006). Le rôle d'une supplémentation en polyphénols sur la dépense énergétique a donc été étudié, mais aucune étude à ce jour n'a observé son effet sur le profil d'activité physique et de sédentarité en contexte de surnutrition.

Cette interaction entre l'ingestion de polyphénols et les paramètres de la dépense énergétique reliés à l'activité physique est d'autant plus intéressante compte tenu de l'effet protecteur d'un mode de vie actif sur la prise de masse corporelle. Une étude menée par Wang et al. (2017) indique que la susceptibilité génétique à prendre de la masse corporelle pourrait être diminuée par l'augmentation de la pratique d'activité physique. En effet, son étude menée auprès d’environ 15 000 adultes supporte un changement de la masse corporelle de seulement 0.01 kg après 4 ans lorsqu’il y a une augmentation marquée de la pratique d’activité physique comparativement à une augmentation de 0.63 kg pour une pratique d’activité physique diminuée et ce, en considérant la susceptibilité génétique à la prise de masse corporelle. Le rôle de l’activité physique dans la prévention d’une prise de poids malsaine a également été étudié par Walhin en 2013. Lors de son étude impliquant une surnutrition d’une semaine à 50% de surplus énergétique, les effets négatifs sur la composition corporelle ont été renversés par la pratique journalière d’une activité physique d’intensité élevée (70% de la consommation maximale d’oxygène) d’une durée de 45 minutes. Au-delà de son impact sur la masse corporelle, la pratique d’activité physique permettrait aussi d’améliorer la composition corporelle, la santé cardiométabolique de l’individu et de prévenir plusieurs autres maladies chroniques, comme les maladies cardiovasculaires, le diabète, l’hypertension, la dépression et l’ostéoporose (Warburton, 2006). Plusieurs revues systématiques indiquent des réductions entre 25 et 50% du risque de développer des maladies chroniques chez les individus pratiquant 150 minutes d’activité physique d’intensité moyenne à élevée de façon hebdomadaire (Pederson, 2015; Stevens, 2014; Waburton, 2010; Tremblay, 2011). Il a été observé que la pratique d’activité physique augmente la longévité chez les individus avec surplus de poids ou obésité (McAuley, 2010). Un individu sédentaire augmentant son niveau d’activité physique entre 75 et 90 minutes par semaine aurait un risque de mortalité réduit de 15% (Stevens, 2014; Wen, 2011). Récemment, certaines études s’intéressent également aux interruptions de la sédentarité comme prédicteur du niveau de santé (Owen, 2010). De plus, un temps sédentaire plus bas est relié à un poids corporel moins élevé (Healy, 2008). Diminuer les comportements sédentaires entraine aussi des bénéfices à court et long terme sur la santé en diminuant entre autres les risques de développer des désordres métaboliques ou une maladie cardiovasculaire (Wilmot, 2012; de Razende, 2014).

La dépense énergétique reliée à l'activité physique en contexte de surnutrition

Comme il est illustré par la Figure 2, la dépense énergétique totale regroupe trois composantes, soit le métabolisme de repos, l'effet thermique de l'activité physique et l'effet thermique des aliments. À ce jour, il est reconnu que le métabolisme de base et l'effet thermique des aliments sont des composantes de la dépense énergétique totale qui augmentent de façon relativement prévisible en contexte de surnutrition. Le métabolisme de base s'est vu augmenté significativement de 5% (Levine, 1999) et de 8% (Ravussin, 1985) lors d'une sunutrition d'une durée de 56 jours et de 9 jours, respectivement. L'effet thermique des aliments augmente de 0 à 30% selon la composition des macronutriments lors d'une surnutrition (0 à 3% pour les lipides, 5 à 10% pour les glucides et 20 à 30% pour les protéines) (Tappy, 1996). Toutefois, l'effet thermique de l'activité physique, défini comme étant la composante de la dépense énergétique totale qui est causée par tout type de mouvement produit par les muscles squeletiques, est présentement moins documenté au sein de la littérature scientifique. Les études de surnutrition ont majoritairement observé les changements au niveau de la dépense énergétique reliée à un exercice volontaire. Ainsi, la dépense énergétique lors d'un exercice de faible intensité et de haute intensité augmente de manière statistiquement significative de 5,6% et 6,4% respectivement après seulement 24h de surnutrition (Dallosso, 1984). Néanmoins, lorsque l'exercice est structuré (ex. : 30 minutes d'exercice sur bicyclette à intensité moyenne), la dépense énergétique totale demeure plus élevée que prévue en contexte de surnutrition (Levine, 1999). Suite à cette dernière observation, Levine et al. (1999) suggère l'existence d'activités involontaires qui seraient modifiées suite à une période de surnutrition, telles que gigoter, maintenir sa posture ou des activités spontanées de la vie quotidienne. Les études de surnutrition considérant cette composante ont pour la plupart été réalisées en laboratoire (Apolzan, 2014; Bray, 2015, He, 2012, Weyer, 2001, Klein and Goran, 2000). Ainsi, le concept selon lequel les changements au niveau de la dépense énergétique, du temps sédentaire et du profil d'activité physique en cours de surnutrition pourraient jouer un rôle important dans la régulation de la balance énergétique a été investigué, mais notre compréhension du phénomène demeure incomplète.

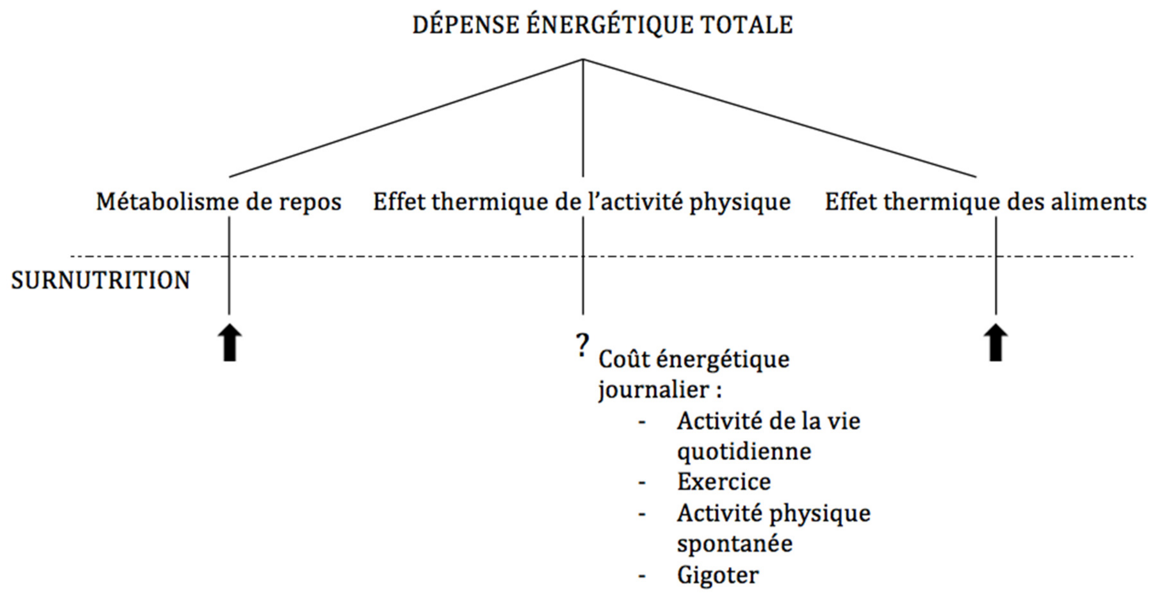

Figure 2. *Effets d'une surnutrition sur les composantes de la dépense énergétique totale*. Image adaptée de Levine et al., 1999.

Il est à ce stade important d'étudier les différentes mesures du profil d'activité physique. De plus, comme il a été soulevé par Levine et al. (1999), il semblerait y avoir une interaction entre la surnutrition et l'activité physique non volontaire, d'où l'importance de mesurer celle-ci en milieu de vie réelle. Pour ce faire, l’accéléromètre est un outil de choix puisqu’il est l’un des outils qui peut mesurer de manière objective l'accélération du corps dans trois plans et ainsi fournir des informations sur la fréquence, l'intensité et la durée de l'activité physique (Warren, 2010). Sa fiabilité, sa validité et sa calibration ont connu des avancées considérables depuis sa première apparition dans le domaine des sciences de l’activité physique en 1983 (Montoye, 1983; Troiano, 2014). En effet, le perfectionnement de plusieurs modèles et d’algorithmes permet dorénavant une meilleure estimation des comportements reliés à l’activité physique (Troiano, 2014). L’utilisation d’un accéléromètre dans un contexte de vie réelle permet d’éviter le biais des questionnaires auto-rapportés qui consiste en une diminution des résultats reliés à la sédentarité et d’une augmentation des résultats reliés à l’activité physique (Clark, 2009). Reiley et al. (2008) ajoutent que l’accéléromètre, comparativement à d’autres outils de mesure tels que la chambre calorimétrique et l’eau doublement marquée, augmente la capacité de relier les variations du profil d’activité à la variation des résultats en matière de santé. L’accéléromètre serait donc un outil de choix en contexte de surnutrition, mais aucun article à ce jour n’a recensé son utilisation et celles des autres outils de mesure. Le premier article de ce mémoire est donc une revue systématique de la littérature observant le profil d’activité spontanée en contexte de surnutrition. Il a pour objectif de vérifier quels outils de mesure sont utilisés et quels sont les effets d’une surnutrition sur le profil d’activité spontanée. Cette première analyse permet de mieux comprendre la balance énergétique dynamique qui existe entre l’ingestion et la dépense calorique.

L’article *Physical Activity, Energy Expenditure and Sedentary Parameters in Overfeeding Studies – A Sytematic Review* sera présentée dans la section qui suit.

Physical activity, energy expenditure and sedentary parameters in overfeeding studies – a systematic review

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Abstract

Background It has been proposed that compensations in physical activity, energy expenditure and sedentary parameters can occur as a result of overfeeding studies in order to maintain body weight; however, the evidence has not yet been systematically reviewed.

Methods The current study systematically reviewed the literature on this subject to determine the common tools used in overfeeding studies and to explore whether overfeeding produces changes in physical activity, energy expenditure and sedentary parameters. Eight electronic databases were searched to identify experimental studies using keywords pertaining to overfeeding, exercise, physical activity and sedentariness. Articles included healthy adults (aged 18-64 years) participating in an overfeeding study that examined at least one parameter of sedentary, energy expenditure or physical activity. Of 123 full-text articles reviewed, 15 met the inclusion criteria.

Results The common tools used in overfeeding studies were doubly labeled water (n = 6), room calorimeter (n = 4), accelerometer (n = 7), pedometer (n = 3), radar sensor (n = 4) and survey (n = 1). Parameters pertaining to energy expenditure increased between 7% to 50% with different overfeeding duration. Physical activity parameters, such as number of steps and spontaneous activity, increased or decreased significantly in three studies, while five studies showed no significant change. Sedentary parameters were examined by only one study and its results were not significant after three days of overfeeding. Methodological issues existed concerning the small number of studies, disparities in sedentary and physical activity parameters and various definitions of free-living experimental conditions and physical activity limits.

Conclusions There is actually a use of many tools and a large variation of parameters for physical activity in overfeeding studies. Contradictory findings showed changes in physical activity parameters following overfeeding and limited findings support the absence of changes in sedentariness. While energy expenditure parameters are more numerous and all show an increase after an overfeeding period, further studies are required to confirm changes in physical activity and sedentary parameters.

Keywords : Overfeeding, physical activity, exercise, sedentariness, energy expenditure, assessment

Background

Obesity is rising at an epidemic rate and is a burden on the population, given that 70% of obese individuals struggle with numerous physiological disturbances such as metabolic complications, inflammation, dyslipidemia, hypertension [1] and increased mortality risk [2]. While a positive energetic balance is a crucial determinant of obesity development, some experimental studies simulated this stage by increasing energy intake beyond energy requirements to maintain body weight. These overfeeding studies aimed to unravel the physiological adaptation to nutrient excess and in particular the evolution of 1) changes in body composition; 2) possible alterations in carbohydrates, lipids or proteins metabolisms; 3) changes in endocrine functions; and 4) changes in energy metabolism and mitochondrial function [3-5].

In this context of experimental overfeeding, it is of major importance to focus simultaneously on energy intake and energy expenditure to observe their mutual influence. Neumann [6] and Gullick [7] were two researchers who performed early overfeeding studies on themselves. At that time, Neumann created the term 'luxus consumption' that is, the production of extra heat as a response to increased food intake. Today, overfeeding studies remained of interest in understanding the first adaptations resulting in weight gain. As recently reviewed, the average weight gain observed in most overfeeding studies are lower than expected, suggesting the presence of mechanisms that counteract the effects of excess energy intake [8]. In this field of investigation, small increases in resting metabolic rate and the thermic effect of food are mechanisms of interest, but only partially explain lower than expected body weight gain [9]. Consequently, some researches focused on adaptive thermogenesis, which includes resting energy expenditure and non-resting energy expenditure and explains the energy dissipation during overfeeding [10].

According to Schoeller [11], energy expended in physical activity (PA) is a component that accounts to a large degree of the variability in weight gain during overfeeding. Nevertheless, as Schutz [8] points out, explaining moderate weight gain only partially, the increase in physical activity thermogenesis cannot be the only mechanism at play. Levine *et al.,* [9] suggested in 1999 the existence of non-exercise activity thermogenesis (NEAT), defined as 'thermogenesis', that accompanies physical activities other than volitional exercise such as the activities of daily living, fidgeting, spontaneous muscle contraction, and maintaining posture when not recumbent. Measuring NEAT was a real challenge at the time. Nevertheless, technological advances put forward by many authors such as accelerometry now allow the measurement of some of these components in a daily lifestyle setting [12]. The aims of the current systematic review are thus 1) to examine the common tools measuring PA, energy expenditure and sedentary parameters in overfeeding studies and 2) to explore whether overfeeding produces changes in these parameters.

Methods

The review was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) statement guidelines [13]. Eligibility criteria are described in Table 1.

Table 1. PICOS (Participants, interventions, comparisons, outcomes, study design)

PICOS component	**Details**
Participants (P)	Adults aged 19-64 years with no eating disorders, no medication, non-smokers or light smokers and a body mass index ≥ 18 kg/m^2
Interventions (I)	Overfeeding intervention (≥ 2 days) including at least one physical activity or sedentary parameter measurement
Comparisons (C)	Pre and post-overfeeding intervention
Outcomes (O)	Overfeeding, overeating, overnutrition, overnourishment, excessive eating, binge eating, physical activity, exercise, sports, sedentariness, physical inactivity
Study design (S)	Randomized control trials, non-randomized controlled trials and non-randomized non- controlled trials, prospective and observation

A search was conducted with no publication date or status restrictions. Studies were identified by searching 8 electronic databases: Medline (1966-present), Embase (1980-Present), CINAHL (1937-present), Scopus (1970-present), Web of Science (1980-present), CAB Abstracts (1973-present), PsycInfo (1806-present), and Cochrane controlled trials (1898-present). A filter was applied for publications in the English language only. The last search was conducted on July 12, 2017.

The following key words and operators were used (search strategy: CAB Abstracts):

1. exp overfeeding
2. exp overeating
3. Overfeeding or over feeding, overeating or over eating, overnutrition or over nutrition, or overnourished or over nourished or excessive eating. (ab, ti)
4. 1 or 2 or 3
5. exp physical activity
6. exp sport
7. Physical activity, or exercise, or sport, or sedentary or sedentariness, or physical inactivity (ab, ti)
8. 5 or 6 or 7
9. 4 and 8

Table 2. Keywords included in the database search strategy

Eating type	**Activity level**
Overfeeding	Physical activity
Overeating	Exercise
Overnutrition	Sports
Overnourished	Sedentary
Excessive eating	Sedentariness
Binge eating	Physical inactivity
Overfeeding	

Titles and abstracts of studies were independently screened by two authors (VG, SS) to determine a first selection of relevant papers. Studies had to meet the following criteria: 1) adult subjects only; 2) presence of an overfeeding protocol; and 3) physical activity, energy expenditure or sedentary level measurements. Disagreements between reviewers were resolved by consensus. Next, a detailed analysis of the papers by one reviewer (VG) led to their inclusion in this review. Studies with no data available relating to overfeeding were excluded. Studies with results only presented in a meeting abstract form were also excluded. Only studies reporting unrestricted physical activity were included, while studies reporting restricted physical activity were excluded (e.g., step count ≤ 4,000 steps/day [14] or structured 30 min of bicycle per day). Studies were excluded on basis of eligibility criteria if there was a weakness in the use of PA tools (e.g., use of indirect calorimetry, but only for the resting metabolic rate) or a weakness in the overnutrition protocol (e.g., protocol duration for one day or ad libitum energy intake protocol).

Data collection was performed by one reviewer. There was no need to contact any authors for additional information.

Table 3. Definition of terms for overfeeding, physical activity and sedentariness

Term	**Definition of variables**
Overfeeding	Energy intake exceeding total energy expenditure over a given period of time
Physical activity	Any bodily movement produced by skeletal muscles that requires energy expenditure
Exercise	Regular and structured subsets of physical activity, performed deliberately and with a specific purpose such as preparation for athletic competition or improvement of some aspect of health
Sedentary behavior	Sedentary behaviors are behaviors characterised by a seated or reclining posture and a low energy expenditure ≤ 1.5 MET during waking hours
Physical inactivity	Activity level insufficient to meet present recommendations

Risk of bias was assessed using the Cochrane Collaboration’s tool for assessing risk of bias for sequence generation, allocation concealment, blinding outcome assessors, incomplete outcome data, selective outcome and other sources of bias [15]. Results are presented in an additional file (Additional File 1). Study selection inclusion was not influenced by the results of the risk of bias assessment. PA, energy expenditure and sedentary parameters were the outcomes of primary interest.

One author (VG) extracted the information into a spreadsheet that included the following: authors, date of publication, sample size, participant characteristics (age, sex, body mass index, body fat index, physical activity details, eating habits), setting, outcome measures (energy expenditure, physical activity parameters, sedentary parameters) and results. Results were converted into international units. Changes in energy expenditure were converted to percentages, if not initially provided.

Results

Figure 1 illustrates the systematic review flowchart following PRISMA guidelines [13]. The databases search yielded 7,739 articles, 2,934 of which were eliminated on the basis of their titles and abstracts alone. The full texts of 123 articles were subsequently retrieved, of which 15 articles gathering 14 trials met the inclusion criteria.

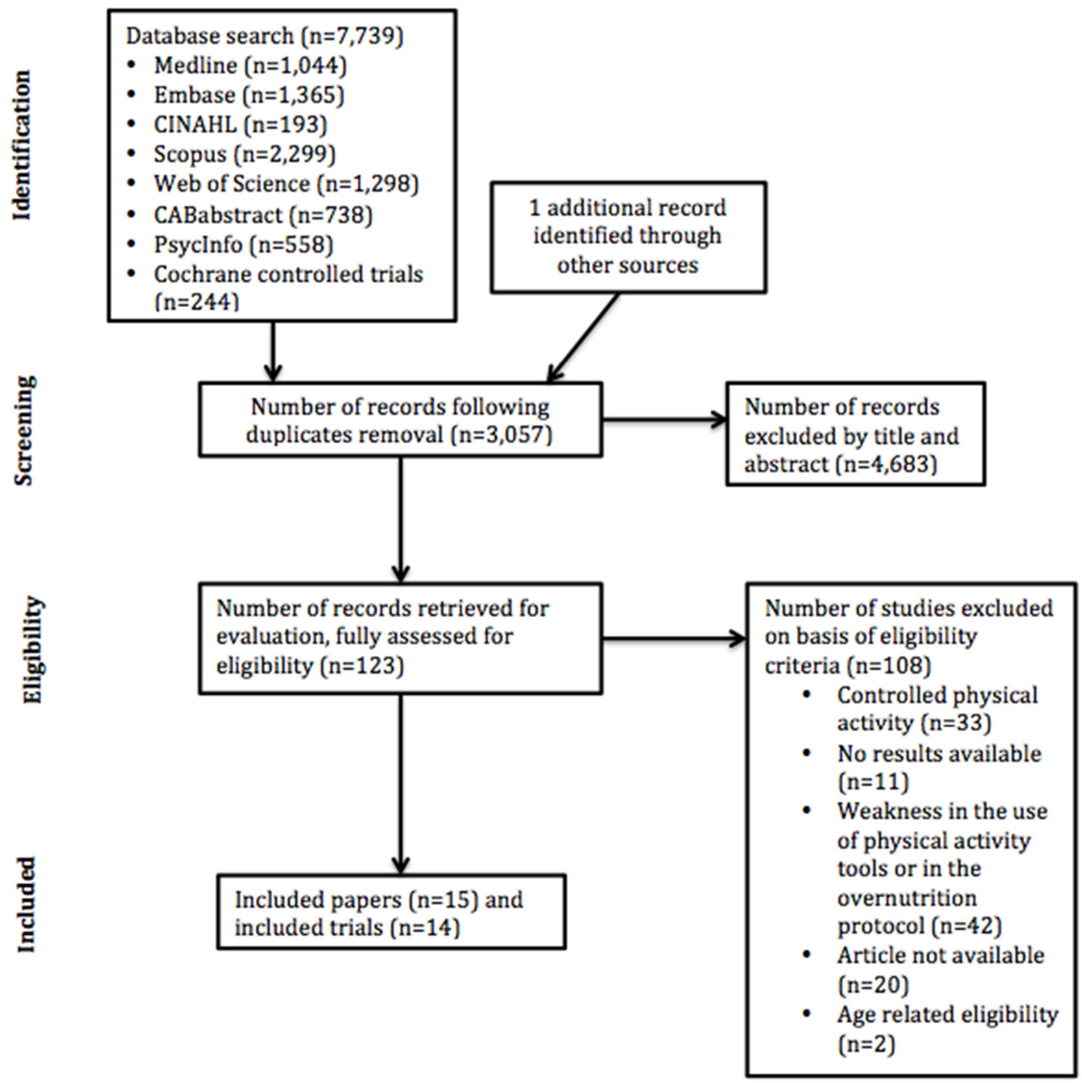

Figure 1. Systematic review flowchart

3.1 Testing protocol

The 14 trials retrieved from this sytematic review took place between 1985 and 2015. The size of the studies varied between 4 [17] and 32 [24, 28] participants and all studies were within-person comparisons over time. Five overfeeding studies used a specific amount of calories for all subjects [9, 16-19]. Other studies opted for a personalized diet based on baseline energy requirements [20-29], calculated with estimations or direct measurements of resting energy expenditure, diet induced-thermogenesis and activity energy expenditure (see table 4). There were variations in overfeeding duration ranging from 2 days [29] to 65 [20, 25] days. Regarding PA guidelines, 6 studies reported instructions of unrestricted PA [16-19, 24, 28], 5 studies asked their participants to avoid any specific PA [9, 20, 23, 27, 29], while the remaining 4 didn't give any instructions concerning the practice of PA at all [21, 22, 25, 26]. Seven studies used accelerometers [16, 18, 20, 23-25, 27] six studies used doubly labeled water [9, 16, 17,19, 20, 26] four studies used a room calorimeter [21, 22, 27, 29] and radar sensor [20, 23, 27, 29], three studies used a pedometer [24, 27, 28] and one study used a survey [25]. Finally, eight studies were in a free-living setting [9, 16, 19, 24-28] and seven were in a laboratory setting [20-23, 17, 27, 29].

Table 4. Studies assessing sedentary, energy expenditure or PA parameters with an overfeeding protocol

Reference (year)	Study design (N, RCT/ nRCT)	Participants characteristics (Age range, sex, body mass index)	Overfeeding protocol	Setting	Physical activity indication	Tools and indicators	Results		
							Pre	Post	Change
Apolzan et al. (2014) [20]	25, RCT	-18-35 yr -16 men, 9 women -19.0-30.0 kg/m^2	1.4x baseline energy requirement* for 65 days 3 groups: - low protein diet (5%) - normal protein diet (15%) - high-protein diet (25%) *Based on 24-h of metabolic chamber direct measurements	Laboratory Participants resided on the inpatient unit for the entire study	Exercise prohibited	Doubly labeled water			
						• Total daily energy expenditure for 9 days (week 7 -8)	n/a	n/a	• Not significant
						• Activity-related energy expenditure, calculated with sleeping metabolic rate and thermic effect of food (metabolic chamber) (kJ/day)	417 ± 81	623± 159	• ↑50%
						Accelerometer			
						• Vector magnitude (counts)	102.6 ±7.97	132.6 ±8.45	• ↑30%
						• Activity energy expenditure (kJ/day) RT3 accelerometer at the waist	281.0 ±29	337.2 ± 26	• ↑20%

						Radar sensor			
						• Physical activity level • Spontaneous physical activity (kJ/day) • Activity (% of active time/24h) On day 1, 14 and 56 of the study	1.47 ±0.06 180 ±21 15.4 ±0.9	1.56 ±0.10 n/a n/a	• ↑6% • Not significant • Not significant
Bray et al. (2015) [21]	25, RCT	-18-35 y -men and women -19.7-29.6 kg/m^2	1.4x baseline energy requirement for 56 days 3 groups: - low protein diet (5%) - normal protein diet (15%) - high-protein diet (25%) *Based on	Laboratory Participants resided in the Pennington Biomedical Research Center. Room calorimeter on week 8.	No indication	Room calorimeter			
						• Total daily energy expenditure (kJ/day)	1993 ±371	2137 ±402	• ↑8 %

			energy expenditure measured by doubly labeled water						
Dirlewanger et al. (2000) [22]	10, RCT	-20-26 y -women -19.3-25.3 kg/m^2	1.4x of baseline energy requirement* for 6 days 1 group, 2 overfeeding diets : - hyperenergetic diet providing 40% excess energy as carbohydrates - hyperenergetic diet providing 40% excess energy as fat * Based on	Laboratory Room calorimeter on day 3	No indication	Room calorimeter			
						• Total daily energy expenditure	n/a	n/a	↑ 7%

			resting energy expenditure measured by 45 to 60 minutes of indirect calorimetry x 1.3						
He et al. (2012) [23]	21, RCT	-42 y -men and women - 33.2 kg/m^2	1.5x weight maintenance* diet for 3 days 1 group * Specific to the inpatient unit and calculated based on body weight and sexe	Laboratory Participants were admitted to the Clinical Research Unit of the National Institute of Diabetes and Digestive and Kidney Diseases	Free walk allowed but exercise prohibited	Accelerometer			
						• Sedentary time (%) • Non-exercice activity (counts/min) Actical monitor worn at the waist, wrist and ankle	70.9 ±12.9 93.9 ±21.5	72.0 ±7.4 68 ±18.4	• Not significant • Not significant
						Radar sensor			
						• Spontaneous physical activity (% of active time/24h)	5.6 ± n/a	5.0 ±n/a	• Not significant
Joosen	25,	-19-36 y	+50% more	Free living	Unrestrict	Accelerometer			

et al. (2005) [16]	nRCT	-women -18.8-24.4 kg/m^2	energy than the baseline energy requirement* for 14 days 1 group * Calculated from basal metabolic rate measured with indirect calorimetry and PA level measured with accelerometry		ed	• Physical activity indicator (Mcounts/day) Tracmor worn at the waist	6666 ±1286	7177 ±1645	• Not significant
						Doubly labeled water			
						• Total energy expenditure (kcal)	10.18 ±0.68	10.58 ±1.00	• Not significant
Klein and Goran (1993) [17]	4, nRCT	-24-35 y -men -21.8-23.4 kg/m^2	+6904 kJ/day* for 8 days 1 group * Baseline indirect calorimetry measurements	Laboratory Participants were free to move around within the clinical	Unrestricted	Doubly labeled water			
						• Total daily energy expenditure (kJ/day) • Non-resting energy expenditure, calculated with resting metabolic rate (indirect calorimetry) (kJ/day)	2 384 ±219 855 ±190	2 808 ± 291 1 171 ± 262	• ↑18% • ↑42%

				research center during the study with an access to a stationary bicycle ergometer.					
Levine et al. (2008) [18]	22, nRCT	-31-47 y -12 women and 10 men -19.0-38.0 kg/m^2	+4184 kJ/day above weight maintenance* diet for 56 days 1 group * Baseline period of 3 weeks during which the dietary intake provided was adjusted to maintain body weight gain weight gain	Free living	Unrestricted	Accelerometer			
						• Walking bouts (n/day) • Time engaged in walking (min/day) • Average distance of a walking bout (miles) • Free-living velocity (mph) PAMS system: 2 accelerometers (CXL02LF3-R, Crossbow technology) and 4 inclinometers	47 ± 6 389 ±106 0.18 ±0.06 1.14 ±0.20	47 ±10 391 ±116 0.15 ±0.06 1.02 ±0.20	• ↓1% • ↓1% • ↓ 21% • ↓ 12% Average of lean and obese group

						(CXTA02, Crossbow Technology) on the trunk			
Levine et al. (1999) [9]	16, nRCT	-25-36 y -12 men and 4 women	+4184 kJ/day* for 56 days 1 group * Based on doubly labeled water measurements	Free living	Exercise prohibited	Doubly labeled water			
						• Total daily energy expenditure (kcal/day) • Nonexercise activity-thermogenesis, calculated with basal metabolic rate and postprandial thermogenesis (indirect calorimetry) (kcal/day)	2807 ±n/a 896 ±n/a	3361 ± n/a 1 235 ± n/a	• ↑12% • ↑38%
Muller et al. (2015) [24]	32, nRCT	-20-37 y -men -20.7-29.3 kg/m^2	1.5x baseline energy requirement* for 7 days 1 group *Based on a dietitian-guided dietary record, resting metabolic	Free living	Unrestricted	Accelerometer			
						• Activity energy expenditure (Kcal/d)	555 ±328	580 ±304	• Not significant
						Pedometer			
						• Steps/day	4785 ±1417	4865 ±1896	• Not significant

			rate with indirect calorimetry and PA with the use of 24 hours heart rate and accelerometry						
Pasquet et al. (1992) [25]	9, nRCT	-20-37 y -men -18.3-23.1 kg/m^2	125 ± 46.6 % of baseline habitual intakes* for 61-65 days 1 group * Based on total energy expenditure measured with doubly labeled water	Free living	No indication	Survey			
						• Spontaneous activity	n/a	n/a	• ↓ 59 %
						Accelerometer			
						• PA indicator At the wrist	4 145 ±1371	2 440 ±816	• ↓ 40 % arm movement counts/24H
Siervo et al. (2008) [26]	6, nRCT	-32-58 y -men -18.8-24.1 kg/m^2	1.6x baseline energy intake* for 21 days 1 group	Free living Participants were free to move	No indication	Doubly labeled water			
						• Total energy expenditure	11.1 ±0.7	12.9 ±0.8	↑ 16%

			* Baseline period of 3 weeks during which the dietary intake provided was adjusted to maintain body weight gain	around the Cambridge area					
Ravussin et al. (1985) [27]	5, nRCT	-22-27 y -men -19.0-23.9 kg/m^2	1.6x baseline energy requirement* for 9 days 1 group *Based on EE within a metabolic chamber plus an estimated 25% for PA	Free living and laboratory Room calorimeter on day 1 and 9 of the study (5m long x 2,5 m wide)	Exercise prohibited	Room calorimeter			
						• Daily energy expenditure (kJ/day)	9.75 ±0.42	10.42 ±0.58 11.79 ± 0.05	• ↑ 7% on the 2nd day • ↑ 21% on the 9th day
						Pedometer			
						• Steps/day	n/a	n/a	• Not significant
						Accelerometer			
						• Activity index	0.03 ±0.00	0.03 ±0.00	• Not significant
						Radar sensor			

						• Spontaneous PA (%)	0.03 ±0.00	0.03 ±0.00	• Not significant
Roberts et al. (1990) [19]	7, nRCT	-23-24 y -men -22.7-25.3 kg/m^2	+ 4 200 kJ/day* for 21 days One group Based on direct measurments of total energy expenditure components	Free living	Unrestricted	Doubly labeled water			
						• Total daily energy expenditure (kJ/day)	13 883 ± 774	14 665 ±678	• Not significant
Schmidt et al. (2012) [28]	32, RCT	-25-35 y -men and women -16.9-25.5 kg/m^2	1.4x baseline energy requirement* for 3 days 2 groups : - obesity prone individuals - obesity resitant individuals * Based on calorimetry energy	Free living	Unrestricted	Pedometer			
						• Steps/day	n/a	n/a	• ↓ (data not available) For both groups

			expenditure measurments						
Weyer et al. (2001) [29]	6, RCT	-21-33 y -men -19.5-25.5 kg/m^2	200% baseline energy requirement* for 2 days 1 group, 2 diets : - ad libitum diet - overfeeding * Based on a 24h in a respiratory chamber after 3 weeks of weight maintenance diet	Laboratory Room calorimeter	Exercise prohibited	Room calorimeter			
						• Daily energy expenditure	n/a	n/a	• ↑ 9%
						Radar sensor			
						• PA energy expenditure (MJ/day)	n/a	n/a	• Not significant

N.B.: values presented are mean ± standard deviation. PA: physical activity

PROTOCOL DURATION	< 1 week	1- 2 weeks	2-3 weeks	> 8 weeks	Study reference
TEE	⬆ ⬆	⬆ ⬆	□ □ ⇧	■ ⇧ ⬆	[9, 16, 17, 19-22, 26, 27, 29]
AEE	■	□ ⬆		⬆ ⬆ ⇧	[10, 20, 24, 29]
Walking parameters	⇩	□ □		⇩ ⇩ ⇩ ⇩	[18, 24, 27, 28]
Other PA parameters	■	□ ■	□	⬆ ⬆ ■ ■ ⇩ ⇩	[16, 20, 23, 25, 27]
Sedentary parameters	■ ■				[23]

TEE: total energy expenditure AEE: activity energy expenditure

⇧ = increase in a free living setting ⇩ = decrease in a free living setting □ = no effect in a free living setting

⬆ = increase in a laboratory setting ⬇ = decrease in a laboratory setting ■ = no effect in a laboratory setting

Figure 2. Effects of protocol duration on energy expenditure, physical activity and sedentary parameters in a free living or a laboratory setting

3.4 Room calorimeter

Concerning room calorimeter, Ravussin [27] showed a daily total energy expenditure (TEE) increase of 7% on the second day and 21% on the last day of a 9-day overfeeding protocol at 160% of maintenance requirements. Other studies have also reported increases in daily TEE of

9% at 2 days using 200% of energy requirement [29]; of 8% at 56 days using 140% individual baseline energy requirement [21]; and of 7% at 6 days using 130% of resting energy expenditure [22]. Measurements were made continuously for 22.5h [27], 23h [22] and 24h [21, 29]. Participants were either not allowed to practice vigorous PA [27] and/or exercise [21], or had simply no indication in term of PA [22, 29]. Radar sensors were once added to the room calorimeter, but PA measurements were not used to estimate total energy expenditure [29].

3.5 Doubly labeled water

Three studies using doubly labeled water revealed an increase in energy expenditure: 18% with an 8-day overfeeding protocol using +6,941 kJ/day [17]; 16% with a 21 days overfeeding protocol using 1.6x baseline energy requirement [26]; the other at 12% with a 56-day overfeeding protocol using +4,184 kJ/day [9]. Other studies showed no significant results with a 56-day overfeeding protocol using 140% of individual baseline energy requirement [20]; 21 days using +4,230 kJ/day [19] and 21 days at +4230 kJ/day [16]. Activity-related energy expenditure has been reported by three studies with an increase of 38% [9], 42% [17] and 50% [20].

3.6 Accelerometer

Using a short duration protocol (7 days overfeeding protocol at 150% energy needs), an increase of 30% in vector magnitude and 20% in activity energy expenditure (AEE) was measured by Apolzan [20]. In longer protocols, activity (arm movement count/24H) showed a 40% decrease at 61-65 days at 125% of baseline habitual intake [25]. In addition, Levine [18] showed decreases of 1% in walking bouts and time engaged in walking, of 12% in free living velocity, and of 21% in average distance of a walking bout (miles) after 56 days of 4184 kJ/day above weight maintenance feeding. Other results have not been significant: activity

AEE at 7 days with 150% of energy needs [24]; sedentary time and non-exercise activity at 3 days at 150% of weight maintenance diet [23]; PA after 14 days at +4230 kcal/day [16]; and activity index at 9 days with 160% of maintenance requirements [27].

3.7 Pedometer

In a protocol of 3 days at 140% of estimated basal energy needs [28], overfeeding was associated with a significant decrease in the number of steps of participants with BMIs between 16.9 and 25.5 kg/m^2 (data not presented). Other studies have shown no difference in step counts at 7 days at 150% of energy needs [24] and at 9 days at 160% of maintenance requirements [27].

3.8 Radar sensor

Radar motion detectors that continuously monitored the subject's movement in the room calorimeter detected an increase in PA levels of 6% at 56 days at 140% individual baseline energy requirement [20]. These radar sensor measurements had no significant results on other PA parameters: activity [20]; spontaneous PA [20, 23, 27]; and physical activity energy expenditure [29].

3.9 Survey

The survey, consisting of a time-allocation survey done by local assistants who recorded activities, postures and pace minute by minute for 24 hours, revealed a decrease of 59% in spontaneous activity using either 61-or 65-day overfeeding protocols at 125% energy requirement [25].

Discussion

The first aim of this review was to investigate the common tools measuring PA, energy expenditure and sedentary parameters in overfeeding studies. Ultimately, 15 papers assessed PA, energy expenditure or sedentariness with 1 tool (n=8) or a combination of 2 to 4 different tools (n=7) using room calorimeter, doubly labeled water, accelerometer, pedometer, radar sensor and survey. The 20 parameters identified are diversified, which provided a wide range of results that can be interpreted following overfeeding but also challenging their comparison. The second aim of this review was to explore whether overfeeding modulate these parameters: PA parameters were maintained, increased and decreased and energy expenditure parameters were increased or maintained. Only one study assessed sedentary parameters and its result indicated a maintenance level.

This systematic review first aimed to determine any preferential use of tools or specific parameters in overfeeding studies. The pedometer was the first tool to be used in an overfeeding study in 1967 [30]. Then appeared the metabolic chamber in 1971 [31]. Decades later, Ravussin *et al.* [27] introduced the accelerometer and the radar sensor and at the same time, a combination of tools for a single study. Finally, the last tool that emerged was the doubly labeled water in 1990 [19]. In this systematic review, these findings show that the accelerometer is the most common tool (n = 7), followed by doubly labeled water (n = 6). However, room calorimeter (n = 4), radar sensor (n = 4), pedometer (n = 3) and survey (n = 1) are less common. A combination of tools was used in 7 studies without any similarities among them.

In terms of parameters, this review identified 20 of them and what emerged was that there was no consensus on preferential parameters. Some tools allowed only one parameter, such as TEE (MJ/day) for the room calorimeter, as well as number of steps for the pedometer. The most popular parameter of doubly labeled water is daily energy expenditure [9, 16, 17, 19, 20, 26], while activity-related energy expenditure or its equivalent is also reported three times [9, 17, 20]. There was only one study that presented parameters of both physical activity and sedentary parameters [23], despite the fact that sedentariness and physical inactivity are two distinct concepts and that both contribute independently to excess body weight gain [32]. In a study conducted by Knudsen [33], inactivity and overfeeding have led to insulin sensitivity impairment. Furthermore, a high amount of sedentariness had an impact on morbidity regardless of PA level [34-36]. However, most of the negative effects of a short-term overfeeding combined with a daily-reduced number of steps are counteracted by physical exercise [14]. Therefore, by not considering PA, exercise, sedentariness and physical inactivity at the same time, there was a lack in the complete interpretation of what was happening in a positive energy balance in adult studies.

The second aim of this review was to explore changes in PA, energy expenditure and sedentary parameters following an overfeeding period. Our results indicated that there might be some changes in PA and energy expenditure parameters while sedentary parameters appeared to be maintained. For PA and energy expenditure parameters, changes were not significant (n = 13), increasing (n = 15) or decreasing (n = 7) with overfeeding, considering that each study could have more than one parameter. The study that appears to have had the greatest impact on PA parameters is that of Alpozan et al. [20] with an increase of 50% in activity-related energy expenditure and Pasquet *et al.,* [25] which showed decreases of about 60% in spontaneous physical activity and 40% in physical activity indicator (counts/day). Other decreases in PA parameters were related to walking characteristics and varied between 1% and 21% [18]. The decreases involved a greater change in the distance traveled (-21%) compared to the daily walking time (-1%), suggesting a less efficient walk and a modulation of energy efficiency. This joins the theory that overfeeding produces change in NEAT [9]. These results also show the importance of evaluating changes in a free living setting.

Increases energy expenditure parameters ranged from 6% to 60% and most were related to the measurement of daily energy expenditure. This wide difference in energy expenditure results could be explained by guidelines given to participants about their PA practice and the space in which the participant could move (Table 4). Interestingly, these increases were observed both in a free living context [9, 20, 26, 27] and when the study was conducted in an inpatient unit [17, 21, 22, 27, 29]. For sedentary behaviors, only one study used this parameter and its changes were not significant [23] just like PA in this study. Other researchers highlight that the duration of protocol and amount of overfeeding are two major factors that produced changes in these parameters [37, 38]. A review conducted by Westerterp [39] using doubly-labelled water found that there was no effect on PA level when overfeeding was lower than twice the maintenance requirements, a finding however in contradiction with some of the study used in the current review [20, 26].

Interesting elements emerge when results were compared according to duration of the overfeeding protocol (Figure 2). Durations of overfeeding varied greatly between different

studies. As mentioned by Joosen and Westerterp [37], the overfeeding period should be long enough to expect an increase in excess body weight. We suggest that it can be the same with changes in PA and sedentary parameters. In fact, it seems that there were more changes when protocol duration exceeded 8 weeks, even if this impact can also be due to a greater number of free living settings with long overfeeding protocols.
In fact, short-duration studies (< 1 week) are mostly done in laboratory. Figure 2 illustrates that TEE was either non-significant or increased with overfeeding. This increase in TEE seemed not to be caused solely by an increase in AEE but was rather multifactorial and possibly linked to the NEAT theory described previously. In fact, three studies performed assessment of both TEE and PA parameters [20, 27, 29]: they all indicated an increase in TEE while PA was maintained or increased (6 to 30%). Walking parameters were maintained and decreased with overfeeding, while other PA parameters were more divergent. For this parameter, a BMI ≥ 30 kg/m^2 could lead to less pronounced changes, as it was found in the Schmidt et al. [28] overfeeding study comparing obesity prone and obesity resistant individuals. Interestingly, Levine and his colleagues carried out the same protocol of overfeeding (time, duration and setting) in 1999 and 2008, except that in the first study, the exercise was prohibited and in the second, physical activity was unrestricted [9, 18]. Again, a mechanism for dissipating excess energy consumption seems to exist, since there was an increase in TEE in the first one and a decrease in walking parameters in the second. These latter results agree with the NEAT theory, but measurements with an accelerometer were therefore incomplete as the non-volitional part could only be verified by radar sensors for a better understanding of its mechanisms.

According to Figure 2, contradictions occur between increase in TEE and the other parameters. In the case of Apolzan et al. [20], there was no modification in total daily energy expenditure, but an increase in vector magnitude, AEE and physical activity while exercise was prohibited. Pasquet et al. [25], on the contrary, observed an increase in daily energy expenditure, but no significant results for any PA results assessed by pedometer, accelerometer and radar sensors. TEE's ability to influence weight gain depends on the increase or decrease in PA and sedentary parameters and hence supports the importance of having precise and complementary parameters. Therefore, this table points out the need to further explore sedentary parameters in long-term overfeeding studies. This is even more important since there was a favorable association between breaks in sedentary time, triglycerides [40] and waist circumference [41], two biomarkers clustered into a metabolic risk.

Studies included in this review did not all agree on the same aims. Some focused on energy expenditure [16, 19, 21, 22, 25-27], or on PA [18, 20, 23, 28] and among these, one study also aimed to measure sedentariness results [23]. Other studies had other aims such as to identify changes in metabolism [17, 29], thermogenic responses [9, 25], basal metabolic rate [29] and leptin levels [22]. These differences among studies could have an impact on the outcomes, which need to be examined.

The different purposes of each paper can explain the variability in the choice of tools and parameters. Kelly *et al.,* [42] pointed out that there is no 'gold standard' in terms of tool choice for PA and sedentary measurements: it all depends on the PA or sedentariness aspect of interest. While the goal of each study differed, it was unexpected to see a consensus regarding the use of a single tool. Nevertheless, questionnaires have limited reliability and validity when they are not for 1) indicating conditions where an increase in PA would be beneficial and 2) monitoring changes in population activity [43]. In fact, self-reporting of PA were overestimated compared to direct measurement tools such as doubly labeled water and accelerometry [44]. This potentially explains why only one study used a survey. If we consider overfeeding studies for the purpose of preventing obesity, then the room calorimeter, which allows the assessment of different components of TEE and thereby, energy substrate utilization, appears to be the tool of choice, as emphasized by Lam and Ravussin [45]. Conversely, if we want to understand why predictive models of weight loss or gain are inaccurate, then measurements of these parameters under free-living conditions could be more accurate. To do so, doubly labeled water and accelerometry are two devices of choice. Furthermore, interest on the combination of tools seems to be emerging [46]. Seven studies in this review used more than one tool for the overfeeding part of the protocol. However, these additions did not necessarily result in improvements in estimating EE [47] but did improve the accuracy of meaningful PA outcomes such as METs/hour and time spent in moderate to vigorous PA [46]. This combination is now important to consider since Pontzer *et al.,* [48] found that compensatory mechanisms that modulate energy expenditure occur with high intensity. In fact, above moderate activity levels, total energy expenditure plateaued.

The current review highlights a wide diversity in participant characteristics subjected to overfeeding protocols. It is now commonly known that confounding factors for energy expenditure include both participant aspects such as age [49], sex [50], genetic [51] and dietary nutriments such as food composition [38, 52, 53] and the type of fat in the diet [54]. With a homogeneous age group of adults, this review did not allow us to observe a difference for this confounding factor. Regarding sex, some articles in this review included only men [17, 19, 24-26, 29], others only women [16, 22], and some of them both [9, 18, 20, 21, 23, 28]. There is insufficient information for interpretation when controlling for energy expenditure and sex in this review, considering that there was only one study examining females and energy expenditure parameters. Finally, unconventional dietary nutriments were performed by Bray et al. [21] with a protein overfeeding and Dirlewanger et al. [22] with a carbohydrate and a fat overfeeding. With the increase of food intake, TEE increase through the processing of ingested food [55]. Protein overfeeding may increase even more TEE by increasing postprandial thermogenesis, which implies a significant bias on the results [55]. A brief period of high fat overfeeding impairs glycemic control [57] as well as carbohydrate overfeeding [53]. These changes in glucose blood concentration interfere with hormonal regulation and lead to fat production and accumulation [53]. Furthermore, some hormones increase TEE, such as leptin [58] which is increased following overfeeding [59].

Limitations

The main limitation in this systematic review concerns the unreported or estimated PA measurements, potentially leading to overestimation of PA measurements. In addition, this makes the comparisons between studies more complex. Furthermore, the PA guidelines the volunteers had during the overfeeding studies which varied from one study to another might have influenced energy expenditure results. Food intake was assessed in both laboratory conditions and free-living conditions. The first is known to be a rigorous method of assessing energy intake and the other may lead to underreporting and biased results [60]. According to

Westerterp [38], the ideal measure of energy expenditure in overfeeding studies may be in non-restrictive conditions and with an increase in caloric ingestion for at least one week. In this case, 60% of studies included in this review were performed in free-living conditions and 66% respected a duration of more than one week. There is clearly a lot more work to be done to elucidate the effects of overfeeding on PA, energy expenditure and sedentariness, starting with direct measurments of these three components in a single study. In fact, no study to date has investigated them altogether.

Conclusions

The investigation of PA, energy expenditure and sedentary measurements in an overfeeding context shows the use of various tools as well as a technological advance putting forward their uses in laboratory but also in free-living context. This systematic review draws a good picture of the literature, as it is performed in eight databases and followed the PRISMA guidelines. Adaptations, both increase and decrease, seemed to occur in PA parameters following overfeeding. This might have been influenced by duration of the overfeeding protocols. An interesting consideration may be an "overfeeding % x duration protocol" factor for a global view of the overfeeding protocol. Unfortunately, 5 studies included in this review gave a specific amount of energy intake in excess instead of an overfeeding percentage, thus making it impossible to compare its effects on energy expenditure, PA and sedentary parameters. As there are a relatively small number of heterogeneous studies included in this review ($N = 15$), these results should be interpreted with caution. Thus, the development of the full potential of certain tools such as the accelerometer must be achieved. There was only one study that specifically assessed sedentariness. A logical next step for future trials would thus be to include sedentary parameters more frequently.

List of abbreviations

AEE: activity energy expenditure

BMI: body mass index

NEAT: non-exercise activity thermogenesis

PA: physical activity

TEE: total energy expenditure

Ethics approval and consent to participate

Not applicable

Consent to publish

Not applicable

Availability of data and material

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors contributions

SS and VG screened the titles and abstracts of studies. VG performed data collections and a detailed analysis of the papers and was a major contributor in writing the manuscript. VG, SS, CS, ML, BS and MEM made substantial contributions to the interpretation of data and for revising the manuscript critically for important intellectual content. VG, SS, CS, ML, BS and MEM read and approved the final manuscript.

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Enjeux du projet

Ce mémoire vise à évaluer à la fois les éléments liés au mode de vie actif et ceux pouvant possiblement renverser la prise de masse corporelle. L'article original observe l'interaction entre une supplémentation en polyphénols et les paramètres d'activité physique et de sédentarité en condition d'une surnutrition de type grignotage. Dans la perspective où ce projet se veut être représentatif d'un environnement obésogène, le profil d'activité sera mesuré en contexte de vie réelle à l'aide de l'accélérométrie.

L'article *Effects of a snacking type overfeeding and a polyphenol supplementation on physical activity, energy expenditure and sedentary parameters* sera présenté dans la section qui suit.

Effects of a snacking type overfeeding and a polyphenols supplementation on physical activity, energy expenditure and sedentary parameters

Running title: Overfeeding, polyphenols and activity profile

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Abstract

Background/Objectives: Early stages of weight gain are accompanied by several thermogenic and metabolic adaptations. Increased physical activity, decreased in sedentary time and ingestion of antioxidants are known to counteract these adaptations. The goal of the current study was to assess sedentary time and physical activity following a snacking type overfeeding in free-living condition and to see the effect of a polyphenol supplementation on those parameters. The hypothesis was that overfeeding would increase physical activity parameters and decrease sedentary time, and that supplementation would magnify these results. **Subjects/Methods:** Seventeen parameters were assessed with accelerometers, using a criterion of a minimum 4 valid days. Twenthy-five healthy men have been selected in a 31 days overfeeding protocol (150% of daily energy expenditure) in a free-living environment. Two-way repeated measures ANOVA were performed to determine the effect of a polyphenol supplementation vs. a non-polyphenol condition over the course of a snacking overfeeding protocol on physical activity, energy expenditure and sedentary parameters. **Results:** There was no statistically significant interaction between polyphenols groups and time points (pre and post overfeeding) for the seventeen parameters of interest. Two parameters changed significantly with overfeeding, regardless of the polyphenol supplementation: time spent running increased by 49.1% in the non-polyphenol group and by 49.0% in the polyphenol group, and resting energy expenditure (kJ*kg-1*day-1), estimated by indirect calorimetry, increased by 2.3% in the non-polyphenol group and by 2.2% in the polyphenol group. Time spent standing, tramping and walking, which could be associated with the notion of non-exercise adaptive thermogenesis, decreased by 5.1% (non-polyphenol group) and 14.8% (polyphenol group) ($p=0.065$). **Conclusions:** This study shows that overfeeding combine to a polyphenol supplementation results mostly in no adaptive changes in

time spent in different physical activity intensities and sedentary parameters. However, overfeeding alone increased time spent in some activities (running, but also standing and trampling) and energy expenditure parameters. Further investigations are needed to confirm this observation.

Introduction

Overfeeding is defined as a caloric intake exceeding total energy expenditure (TEE), thus producing a positive energy balance. This phenomenon became more present in western societies given a multitude of factors, including the increased of daily snacks in the last decades (Dunford, 2017). In the United States of America, snacks have been shown to comprise approximately 25% of daily energy intake, thus revealing a great influence in the development of obesity (Piernas, 2010; Hess, 2016). Besides the snacking situation, the quality of ingested food is important to consider. It was recently suggested that polyphenols, antioxidants of a vegetable origin, could prevent small increases of body weight during overfeeding (Farhat, 2017). In addition, increase in metabolic flexibility following a high-fat meal and also an increase in fasting and postprandial energy expenditure was found after only 3 days of a polyphenol supplementation (Most, 2014). However, the impact of polyphenols on activity profile in the context of overfeeding is unknown.

Until this day, the prediction of weight gain from energy ingested in an overfeeding environment remains inaccurate (Muller, 2016). Overfeeding effect on energy dissipation is bigger than the one expected (Lam, 2016). A review conducted by Durhandar (2015) showed that there is up to 96% less weight gain than predicted by metabolic calculators. This inaccuracy is accounted by behavioural compensations through both changes in dietary intake and energy expenditure changes (Durhandar et al., 2015). Some overfeeding studies have taken up the challenge to understand these energy expenditure changes while measuring physical activity and sedentary parameters. Overall, a total of 17 different indicators are in use and they suggest that there might be some changes in physical activity (PA) parameters following an overfeeding period (Giroux et al., 2018). In this review, increases were noted in TEE and activity energy expenditure (AEE) and both increases and decreases were observed in other PA parameters (i.e. number of steps, physical activity level, etc.). However, each study has between 1 and 7 indicators at a time and very rarely considers sedentariness. Sedentary behaviour assessment is gaining popularity since it is longitudinally associated with overweight, obesity and certain diseases, independently of the level of PA (Su, 2017). He et al. (2012) were the only ones to monitor sedentariness in a short overfeeding protocol (3 days) carried out in laboratory settings. They found maintenance in sedentary time (% of daily time) and non-exercise activity (counts/min). Thus, there is no exhaustive concomitant examination of sedentary and PA behaviours in daily living following a long-term overfeeding period.

The current study conducted in free living condition aim to report a broad range of accelerometry parameters in overfed subjects using a polyphenol supplementation or a placebo supplementation. It is predicted that overfeeding would result in an overall decrease in sedentary time and increases in energy expenditure and PA parameters and that these changes will be of a different magnitude in the group with the polyphenols supplementation.

Method

Protocol – This randomized controlled study [polyphenols group (PG) vs. non-polyphenols group (NPG)] included a basal reference period of 8 days (usual diet) and 31 days of overfeeding. During these periods, subjects were asked to pursue a normal lifestyle. There was no change requested in PA and eating habits, apart from snacks included in the overfeeding protocol. Subjects added foods rich in fat and sucrose to their usual feeding representing an additional contribution of 50% of daily energy expenditure. A snacking overfeeding type was chosen to reflect a more occidental lifestyle. Snacks were provided to the participants and consists of chocolate breads, chocolate bars, crisps and cola-sweetened soda cans. The amount of extra calories was determined by an equation based on the metabolic rate assessed by indirect calorimetry completed on day 7 of the basal period and a 1.4 physical activity level (low level) as follows: daily energy expenditure = metabolic rate x PA level. The daily energy expenditure was than multiplied by 50% to give the energy value of overfeeding. Ingestion of a polyphenol or a placebo supplementation started on the fist day of the overfeeding period. The supplementation consists of 2 g/day of procyanidins (≥ 15%), anthocyanins (≥ 2%) and resveratrol (≥ 0.100 ppm) in 2 doses, 5 capsules in the morning with a full glass of water after breakfast and 5 capsules at the end of dinner in PG and placebo capsules in NPG. Polyphenolic extracts were obtain from red grapes from the Languedoc-Roussillon region. After the study, subjects were offered a professional follow-up to lose any excess weight they had gained.

Subjects – Healthy men, aged between 18 and 55 years old, were recruited through advertisements in the local newspapers, posters in public area (university and hospitals), extraction from the volunteer file of the CRNH-RA database and through the communication service of the Hospices de Lyon. None of the subjects smoked nor had any recent illness or history of an endocrinopathy according to physical examination, medical history and laboratory tests. The subjects were known to have maintained their body weight constant over three months before the study. The study was conducted in the CRNH-Rhône Alpes, Pierre Bénite, France after being approved by the local ethics committee (CPP Sud Est IV). It was registered on the clinicaltrials.gov site as NCT02145780. Written informed consent was obtained from the subjects.

Measurements of sedentary and physical activity parameters – Tri-axial accelerometers Actigraph GT3X (Actigraph, Pensacola, USA) were worn from baseline (day 1 to day 8) and from day 21 to day 28 of the overfeeding period, at the waist. The subjects were instructed to wear the accelerometers when awake throughout each of the two recording weeks and to remove them only during sleep, shower, bath and aquatic activities. Acceleration signals were acquired at 50 Hz. After the recording weeks, data were downloaded and converted to activity-counts per second and steps per day using manufacturer software (Actilife 6.13 Pensacola, USA). Raw triaxial acceleration data and activity-counts were used to define time spent lying, tramping, sitting slouched, sitting toned, standing, walking, biking or running using a validated automatic activity-recognition algorithm, (Garnotel et al. 2018). Time spent lying included the none-wear and sleep. Time spent standing, trampling and walking were gathered and presented NEAT index (Table 2). Time spent sitting and standing in Table 2 gathered the recognition of sitting slouched and toned and the recognition of standing and tramping respectively. Time spent in light, and moderate-to-vigorous activities were further calculated from PAEE using cut-points of 1.5 and 3 METs respectively. Identification of nocturnal sleep and of non-wear periods were done using an automated validated algorithm (Tudor-Locke et al. 2014; Barreira et al. 2015). Time spent in very light intensity represented cut-points under 1.5 METS. Energy expenditure parameters included resting energy expenditure (REE), physical activity energy expenditure (PAEE) and total energy expenditure (TEE), were all expressed in kJ*kg-1*day-1. REE was assessed by indirect calorimetry the first day of basal and overfeeding period (Quark (Cosmed, Rome, Italy)). AEE was expressed per minute using an activity-specific energy expenditure model, which has been shown to present a better accuracy than models based on activity-counts only, as compared to the doubly-labeled-water reference method (Garnotel et al. 2018). TEE, considered as the sum of REE, PAEE and diet-induced thermogenesis (DIT), was calculated as follows: (REE+PAEE)/0.9. Additional parameters were time spent in activity bouts of moderate-to-vigorous activities longer than 30 minutes and total duration of sedentary bouts (i.e. lower cut-point set to 100 counts per minutes) during wake wear time longer than 30 minutes. Subjects were excluded from the analysis if they wore the device for less than 4 valid days (i.e. at least 10 hours of a daily wear time) in each of the two recording weeks (Colley et al. 2010). All sedentary/activity time data were reported in minutes per day.

Statistical analyses – All analyses were conducted with SPSS (version 25) (IBM, Armonk, USA). Subject's characteristics data are expressed as means and standard deviations. Data were distributed normally and a two-way repeated measures ANOVA was conducted to compare the effect of a polyphenol supplementation (PG vs. NPG) at two time points (before vs. during the overfeeding period) on different PA and sedentary parameters. Differences between estimates were tested for statistical significances, which was established at $p < 0.05$.

Results

Of the initial 42 participants, 25 met the inclusion criterion of 4 valid days measured by accelerometer, 12 in the NPG and 13 in the PG. A baseline physical and metabolic characteristic of the study population is summarized in Table 1.

Table 1. Baseline characteristics of the study population

	NPG (n=12)	PG (n=13)	All (n=25)
Age (years)	32.1 ± 27.5	31.2 ± 11.4	31.7 ± 19.6 (18.6-54.3)
Height (m)	1.81 ± 0.06	1.8 ± 0.1	1.8 ± 0.7 (1.7-2.0)
Body weight (kg)	82.3 ± 27.5	79.8 ± 97.9	81.0 ± 7.7 (76.0-95.7)
Body mass index (kg/m^2)	25.1 ± 51.4	24.8 ± 41.4	24.9 ± 1.4 (22.8-27.3)
Body fat (%)	25.3 ± 6.6	26.1 ± 5.7	25.5 ± 6.0 (35.5-14.6)

NPG: Non-polyphenol Group; PG: Polyphenol Group. Mean ± standard deviation (minimum – maximum). Non-significant difference between groups: all p-values are > 0.05.

PA, energy expenditure and sedentary parameters between subjects taking or not the polyphenol supplementation are presented in Table 2. No significant interaction between polyphenol groups and time for any of the 13 sedentary and PA parameters emerged. When testing the main effect of groups, polyphenol supplementation showed a statistically significant difference in activity bouts (moderate-to-vigorous activities longer than 30 minutes). Concerning the main effect of time, two parameters increased with overfeeding: time spent running increased (49.0% in the NPG and 49.1% in the PG) (p=0.008) and resting energy expenditure (2.3% in the NPG and 2.2% in the PG) (p=0.033).

Table 2. Changes in physical activity and sedentary parameters following overfeeding

	NPG		**PG**		**ANOVA Two-way**											
					GROUP				**TIME**				**GROUP x TIME**			
	PRE	POST	PRE	POST	SS	df	F	Sig.	SS	df	F	Sig.	SS	df	F	Sig.
Walking parameters																
# steps, steps/day	6305 ±1606	6541 ±1 859	7574 ±4035	7749 ±3269	19 135 802	1	1.217	0.281	526 024	1	0.428	0.519	12 130	1	0.010	0.922
NEAT index	231.3 ±105.1	219.6 ±122.4	283.5 ±101.6	241.5 ±112.0	17 137	1	0.780	0.386	9 015	1	3.762	0.065	2 865	1	1.195	0.286
Time spent in different activities (min/day)																
Lying	550.2 ±185.4	615.0 ±196.4	503.5 ±149.9	536.3 ±192.4	208 779 318	1	1.053	0.316	84 216 395	1	2.134	0.158	4 965 970	1	0.126	0.726
Sitting	632.5 ±175.7	579.6 ±176.6	638.2 ±171.9	642.7 ±180.0	14 755	1	0.295	0.592	7 277	1	0.595	0.448	10 265	1	0.839	0.369
Standing	178.5 ±90.4	166.4 ±87.3	202.4 ±66.3	167.0 ±91.3	1 847	1	0.147	0.705	7 113	1	4.134	0.054	1 728	1	1.004	0.327
Walking	52.5 ±21.8	52.9 ±39.6	80.8 ±57.8	74.4 ±46.4	7731	1	2.162	0.155	113	1	0.419	0.473	143	1	0.533	0.473
Running	5.1	7.6	5.3	7.9	1	1	0.01	0.891	80	1	8.326	0.008	0.1	1	0.013	0.910

	±4.0	±5.6	±5.5	±6.8			6									
Biking	9.8 ±12.3	18.2 ±22.6	9.4 ±9.0	11.4 ±8.5	157	1	0.69 0	0.415	336	1	1.977	0.173	125	1	0.736	0.400
Intensities parameters																
Sleep and none-wear (min/day)	655.7 ±57.2	639.6 ±52.1	688.7 ±63.4	684.4 ±76.6	6 296	1	3.13 4	0.090	2 688 616	1	0.659	0.425	15 946	1	0.216	0.646
Very light (min/day)	556.15 ±74.7	559.2 ±146.1	488.3 ±81.9	511.7 ±77.6	41 534	1	2.87 5	0.103	2184	1	0.430	0.518	1 298	1	0.256	0.618
Light (min/day)	168.5 ±71.7	168.4 ±102.5	179.6 ±67.3	155.2 ±64.5	15	1	0.00 1	0.971	1 872	1	1.524	0.230	1 855	1	1.510	0.232
Moderate to very vigourous (min/day)	59.5 ±24.9	72.7 ±44.1	83.3 ±70.6	88.7 ±58.8	4 931	1	0.98 1	0.332	1 074	1	1.760	0.198	191	1	0.313	0.581
Activity bouts	1.3 ±3.6	1.2 ±1.7	5.0 ±6.7	5.8 ±7.4	218	1	4.71 9	0.040	1.4	1	0.109	0.744	2.6	1	0.204	0.656
Energy expenditure (kJ/kg·day)																
AEE wmlm	34.2 ±9.5	36.4 ±15.4	39.1 ±14.2	39.0 ±11.4	177	1	0.63 3	0.434	14	1	0.284	0.599	16	1	0.330	0.571

REE wmlm	89.3 ±7.4	90.6 ± 6.4	91.6 ±7.7	94.2 ±7.8	109	1	1.06 7	0.312	50	1	5.176	0.033	5	1	0.492	0.490
TEE wmlm	137.1 ±10.0	141.6 ±22.0	146.7 ±20.1	148.7 ±17.0	864	1	1.59 7	0.219	132	1	1.364	0.255	19	1	0.194	0.664
Sedentariness																
Total duration of sedentary bouts	38.5 ±40.2	38.7 ±57.4	32.5 ±52.3	28.3 ±42.8	838	1	0.26 5	0.612	53	1	0.033	0.856	59	1	0.038	0.848

Data are means ± standard deviation; NPG: none-polyphenol group; PG: polyphenol group; Activity bouts: time spent in bouts of moderate-to-vigorous activities longer than 30 minutes; AEE, activity energy expenditure; TEE, total energy expenditure; Total duration of sedentary bouts: lower cut-point set to 100 counts per minutes; J: Joules. Significant effect using ANOVA : p<0,05.

Discussion

The primary finding from this paper is that there was no change in PA, energy expenditure and sedentary parameters resulting from the polyphenol supplementation over the course of a 31 days of overfeeding. However, when looking at the overfeeding impact only, there were statistically significant results for time spent running and resting energy expenditure, which increase over time. The validity of these results is strong in view of the fact that all subjects had mostly the same activity profile at the beginning of the study: there is only one parameter that has come out significant for the difference between groups (activity bouts).

The first aim of this study was to observe the effect of a combination of polyphenols and overfeeding on PA, energy expenditure and sedentary parameters. The current study is the first to observe the potential protective impact of polyphenol supplementation on weight gain in the context of an overfeeding study and this, on a broad range of PA and sedentary parameters. Promising findings showed that polyphenols can mimic the effects of calorie restriction (Timmers, 2011) and increase energy expenditure (Most, 2014; Dullo, 1999). The expected effects of polyphenols are therefore not to stimulate total energy expenditure through PA (AEE), but from other components, such as REE and diet-induced thermogenesis (DIT). As expected, no interaction was found between the polyphenol groups and time for the PA and sedentary parameters. Nevertheless, the current supplementation did not yield conclusive results for REE. As a majority of reviews reported increases in resting energy expenditure with a supplementation in polyphenols (Vaughan, 2014; Mele, 2017; Mahendra, 2016) it is therefore not the case in the present study involving a positive energy balance. As for DIT, this component's measurement wasn't considered in this study. A previously published review associated the consumption of polyphenols with an increase in DIT (Shixian, 2006), while other studies reported no effects (Lonac, 2012; Coe, 2013).

The second aim of this study was to evaluate the impact of overfeeding on a wide range of PA, energy expenditure and sedentary parameters. Energy expenditure is one of the most popular parameter assessed with various tools in overfeeding studies. Over time, doubly labelled water (Apolzan, 2014; Joosen, 2005; Klein and Goran, 1993; Levine, 1999; Siervo, 2008; Robert, 1990), accelerometer (Apolzan, 2014), room calorimeter (Bray, 2015; Dirlewanger, 2000; Ravussin, 1985 and Weyer, 2001) and radar sensors (Weyer, 2001) were use. Until recently, accelerometry was less common in overfeeding studies despite that its assessment of energy expenditure has been validated compared with the use of doubly labelled water in lean young men with various fitness levels (Villars, 2012). Overfeeding in the present study did not favor increased in total energy expenditure, which is similar to some previous studies [Apolzan, 2014; Bray, 2015; Dirlewanger, 2000; Klein and Goran, 1993; Levine, 1999; Levine, 2008; Pasquet, 1992; Siervo, 2008; Schmidt, 2012], but not all [He,2012; Joosen, 2005; Muller, 2015; Roberts, 1990]. The current state of literature shows that the components of TEE (Figure 2) either remain stable or increase from even the first days of a positive energy balance (Vinales, 2016).

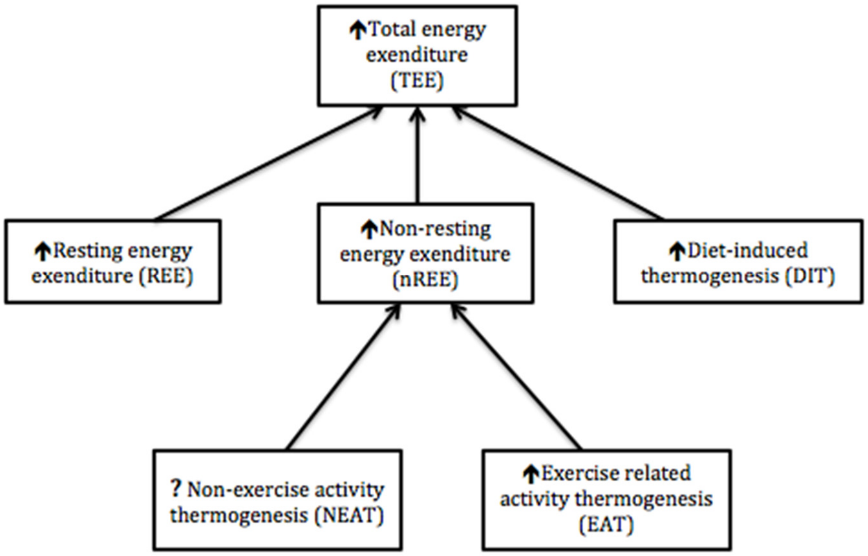

Figure 1. *Total energy expenditure and its components during overfeeding*

First, resting energy expenditure (REE) increases between 5% (Levine, 1999) and 8% (Ravussin, 1985) following an overfeeding period. Results from the present study implie a smaller increase of 2.2-2.3%. Second, non-resting energy expenditure (nREE) is known to participates in 10% of the total increase of total energy expenditure following overfeeding (Cuthbertson, 2017). This component include non-exercise activity thermogenesis (NEAT), defined as activities of daily living, fidgeting, spontaneous muscle contraction and maintaining posture when not recumbent, and exercise related activity thermogenesis (EAT), which is the energy expended while doing a voluntary exercise. The current study shows no significant differences in this component (described as AEE in Table 4). If we take nREE components individually, EAT can reach 19% increase (Ravussin, 1985). However, this increase wasn't measurable since the participants in the present study were sedentary from the beginning and were asked to continue their activities of daily living. With regards to NEAT, what happens in an overfeeding context is unclear based on currently available evidence. It does not seem that NEAT played a role in the regulation of energy expenditure in the present study. Finally, a review observed increases between 0 and 30% of DIT (Tappy, 1996).

The PA components included activities and intensities parameters. It seems that overfeeding has an independent impact on time spent in specific parameters. Time spent running was statistically increased. This study also shows that with a greater statistic power, a difference could be demonstrated with time spent standing ($p = 0.054$) and time spent in a combination of activities (standing, tramping and walking ($p=0.065$)) that are close to the NEAT definition. The extensive assessment of time spent in different activities in an overfeeding context is crucial to understand not only how many calories are expended, but also the actual activities performed. Decrease in standing, trampling and walking during this overfeeding study is consistent with those of Levine et al. (2008) who found a decrease in time engaged in walking in lean and obese subjects in free living condition. Subjects from that study also decreased their average walking distance substantially, by 21% following 56 days of overfeeding. Such a decrease was also reported for free living subjects (Schmidt, 2012) after only three days of overfeeding while other overfeeding studies (7 and 9 days) found no change under free living conditions (Muller, 2015 and Ravussin, 1995). Intensity parameters (Table 2), going from very light to very vigourous were assessed for the first time in an overfeeding study and they showed no significant changes.

Measuring sedentary time is gaining popularity since interruptions in sedentary time is associated with lower waist circumference, body weight gain, diabetes, cardiovascular disease and death (Healy, 2008) (Wilmot, 2012). In the current study, it seems that a relatively long term overfeeding had no impact on sedentary bouts (Table 2). This finding is in agreement with a previous short-term overfeeding study (3 days) that did not result in an overall change in sedentary time neither (He et al. 2012).

Limits regarding the present study are the relatively small number of subjects, which limits the statistical power, and the fact that participants were not blinded to the snacking diets. This study includes a single dose of supplements (2g/day) and percentage increase in energy ingestion (150%), which gives only one perspective of a polyphenol intervention in an environment that favors weight gain. As mentioned earlier, some components of the NEAT aren't monitored with the use of accelerometers. Also, this current study doesn't take into consideration activities performed while participants were not wearing their accelerometers. Despite these limits, a multitude of parameters were measured in a long-term snacking overfeeding study in free-living conditions and the inclusion of a polyphenol supplementation is a novelty in the overfeeding field. Finally, inclusion of both PA and sedentary parameters is a more complete consideration of the factors that can influence overall health.

In summary, there was no interaction in the context of overfeeding between a polyphenol supplementation and activity profile established on walking parameters, time spent in different activities and intensities, energy expenditure and sedentary time. What happens with more subtle elements of PA, such as fidgeting, spontaneous muscle contraction and maintaining posture remains to be established.

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Conflict of Interest

Conflict of interest: the authors declare no conflict of interest.

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Discussion

Les mesures du profil d'activité spontané en contexte de vie réelle lors d'une surnutrition ont débuté avec l'étude de Pasquet et ses collaborateurs en 1992. N'ayant donné aucune indication spécifique par rapport à la pratique d'activité physique aux participants, ils remarquent alors une diminution de l'activité physique spontanée de près de 60% après 65 jours de surnutrition. Ce résultat impliquait une influence de l'ingestion calorique sur la dépense énergétique, alors que ces deux composantes étaient alors considérées comme indépendantes l'une de l'autre. Les études de surnutrition qui ont suivi ont rapidement mis en lumière ce phénomène en observant que les calories en excès à elles-seules n'étaient pas suffisantes pour prédire la prise de masse corporelle. Bessessen et al. (2011) et Durhandhar et al. (2015) constatent qu'il y a un manque concernant ces modèles de prise de masse corporelle, en partie parce qu'ils ne tiennent pas compte des compensations comportementales. Il se trouve que la prédiction de la prise de masse corporelle est souvent erronée. Cette dernière est plus haute que les résultats obtenus, de par une sous-estimation de la dépense énergétique journalière. Levine et al. (1999) met de l'avant que même avec un certain contrôle au niveau de l'activité physique (ex. exercice volontaire interdit), la dépense énergétique fluctue de façon anormale. Dans son étude où l'apport et la dépense énergétique étaient rigoureusement mesurés par l'eau doublement marquée et la calorimétrie indirecte, la prise de masse adipeuse était plus basse que prévue après 8 semaines de surnutrition (Levine, 1999). Cette diminution était alors expliquée par une augmentation de la dépense énergétique comptant pour 14% de la thermogénèse alimentaire, 8% du métabolisme basal, 45% de l'activité physique volontaire et 33% de l'activité physique non structurée. Depuis, de plus en plus d'études de surnutrition s'intéressent aux paramètres d’activité physique et de sédentarité en plus de la dépense énergétique (Giroux, 2018). À ce jour, aucune étude n’avait mesuré à la fois des paramètres de dépense énergétique, de sédentarité et d’activité physique à différentes intensités ainsi que différents types d’activités. Le projet de ce mémoire détenait donc une approche globale en considérant dix-sept de ces paramètres. Également, l’observation de leurs interactions avec une supplémentation de polyphénols en contexte de surnutrition aura été une stratégie d’intérêt pour potentiellement observer son effet sur le profil d’activité spontanée.

Rappel des résultats

L’objectif du projet de ce mémoire était dans un premier temps de vérifier l’impact d’une surnutrition et d’une supplémentation en polyphénols sur le temps passé à réaliser différentes activités et différentes intensités, les périodes d’activités et de sédentarité et les composantes de la dépense énergétique. Après analyse, aucune interaction significative entre le temps et la présence ou non de supplémentation n’est observée pour l’ensemble de ces paramètres d’activité physique et de sédentarité. Dans un deuxième temps, l’effet d’une surnutrition à elle-seule a été observé sur différents paramètres mesurés. Plus précisément, deux paramètres ont augmenté suite à la surnutrition, soit le temps de course (+49.0% dans le groupe placebo et +49.1% dans le groupe polyphénols) et la dépense énergétique de repos (+2.3% dans le groupe placebo et +2.2% dans le groupe polyphénols). Il y aurait également une tendance à des diminutions pour le temps passé debout et l’indice NEAT qui correspond au temps passé debout, au piétinement et à la marche et ce, vers la fin de la surnutrition. Toutefois, cette observation doit être validée par des études complémentaires.

Surnutrition et profil d'activité spontanée

Le rôle du profil d'activité spontanée dans la prise de masse corporelle demeure un sujet d'intérêt au niveau de la recherche scientifique. Les différents chercheurs soulignent l'importance d'axer la recherche sur le bilan énergétique et non pas sur une seule composante de l'équilibre énergétique (Blair, 2015). Bien qu'un nombre grandissant d'études de surnutrition révèle des changements potentiels au niveau des paramètres d'activité physique et de sédentarité, à l'inverse, très peu d'études ce sont intéressées à l'impact de la composition de la diète sur le profil d'activité spontanée. Kien et al. (2013) seraient les premiers à avoir vérifié le type de gras ingéré et son impact sur l'activité physique. Ils constatent que l'activité physique mesurée par accélérométrie augmente de 12 à 15% et que la dépense énergétique de repos augmente de 3,0 à 4,5% avec une diète basse en acide gras palmitique. Étant donné que le protocole de surnutrition du projet de ce mémoire impliquait une plus haute teneur en acide gras palmitique, cela pourrait expliquer en partie la raison pour laquelle il y avait très peu de changements détectés par accélérométrie après la surnutrition. L'impact de la composition de la diète sur le profil d'activité spontanée demeure une question importante puisqu'il est de plus en plus mis en évidence que les changements au niveau du NEAT lors d'une surnutrition entraineraient une prise de masse adipeuse moins élevée (Levine, 2018). Étant donné que l'indice NEAT mesuré au cours de ce projet diminue, mais de façon non significative avec la surnutrition, on aurait pu s'attendre à observer une prise de masse adipeuse plus marquée. Il est à noter que ces travaux, en collaboration avec les co-auteurs de l'article principal de ce mémoire, sont en cours.

Les changements du profil d'activité spontanée ne prédiraient pas seulement la composition corporelle lors de la surnutrition, mais plusieurs années après cette période. Récemment, Creasy et al. (2018) ont observé que le gain de masse adipeuse sur une période de 5 ans est significativement corrélé avec les changements du comportement sédentaire lors d'une suralimentation à court terme (3 jours) à 140% du maintien de la masse corporelle. Une étude différente portant sur la même étude initiale a trouvé qu'une faible oxydation des graisses la nuit suite à une période de suralimentation semble être associée à un phénotype métabolique favorisant la prise de masse corporelle (Rynders, 2017). Dans la mesure où les participants du projet de ce mémoire ont maintenu leurs profils d'activité physique et de sédentarité en cours de surnutrition, il serait intéressant de comparer l'évolution de la prise de masse adipeuse post surnutrition avec celle de participants qui ont vécu des changements au niveau de ces paramètres lors d'autres études de surnutrition, comme c'est le cas pour Apolzan et al. (2014), Klein and Goran (1993), Levine et al. (2008), Pasquet et al. (1992) et Schmidt et al. (2012). Dans cette optique, il serait possible d'ajouter des données probantes à cette prédisposition du gain de masse corporelle qui serait démasquée par la suralimentation.

Supplémentation et activité physique

Tout récemment, le Comité Olympique International a partagé sa nouvelle définition d'une supplémentation nutritive, soit « un aliment, un composant alimentaire, un nutriment ou un composé non-alimentaire qui est volontairement ingéré en plus du régime alimentaire habituellement consommé dans le but d'obtenir un bénéfice spécifique en termes de santé et/ou de performance » (Maughan, 2018). Cette supplémentation se fait pour plusieurs raisons : 1) aider à la récupération après l'entrainement, 2) acquérir des bénéfices pour la santé, 3) traiter une maladie et/ou 4) compenser pour une alimentation pauvre (Maughan, 2013). Les effets d'une supplémentation sur les paramètres d'activité physique ont surtout été étudiés chez le sportif (Bahrke, 2002; Momaya, 2015) ainsi que chez la personne âgée (Kalyani, 2010; Muir, 2011; Liao, 2017). Aucune étude à ce jour, autre que ce projet portant sur les polyphénols, n'a évalué l'effet d'un supplément sur le profil d'activité en milieu de vie réel chez l'adulte sédentaire. Toutefois, certaines études utilisant une supplémentation en polyphénols se sont penchées sur l'observation de marqueurs biochimiques de santé et d'adiposité. Bell et al. (2011) observent un meilleur profil lipidique chez des sujets ingérant 300 mg d'une formulation en polyphénols de la classe des flavonoïdes. Il est à noter que la durée du protocole était alors de 8 semaines, soit deux fois supérieur à celle du projet de ce mémoire (31 jours). Il se pourrait donc que la durée du présent projet ainsi que la formulation de la supplémentation en polyphénols ne soient pas optimaux afin d'observer des effets sur les paramètres de dépense énergétique, d'activité physique et de sédentarité. Plus de travaux sont nécessaires afin d'identifier la durée de consommation et la composition des suppléments optimaux. À titre d'exemple, une étude utilisant 800 mg par jour d'une supplémentation en polyphénols de la classe des gallates d'épigallocatéchines, extrait du thé vert, cette fois-ci d’une durée de 6 semaines, n’observe pas de changements significatifs des marqueurs biochimiques (Brown, 2011).

L’intérêt d’une supplémentation en polyphénols réside dans ses propriétés bénéfiques pour la santé. Bien que les propriétés antioxydantes des polyphénols seraient protectives contre les effets du stress oxydatif démontré lors d’études in vitro (Gonzalez-Castejon, 2011), il ne semblerait pas y avoir d’effets sur le stress oxydatif lorsque ingéré chez l’humain (Lotito, 2004) de par une détoxification trop rapide par le foie (Savini, 2013). Néanmoins, ces molécules deviennent une espèce chimique nucléophile qui activera certains facteurs de transcription, dont le Nrf2. La synthèse du glutathion étant favorisée par le Nrf2, cela permet de détoxifier les peroxydes endogènes et de maintenir le statut redox cellulaire chez l’humain (Pedret, 2012). Il est reconnu que la surnutrition conditionne plusieurs réactions métaboliques entrainant un déséquilibre du potentiel rédox chez l’humain (Samochat-Bonet, 2012; Boden, 2015). Une revue de la littérature a d’ailleurs mis en lumière qu’une consommation riche en polyphénols de la classe des flavonoïdes aurait le potentiel d’améliorer le potentiel rédox dans une population avec obésité (Gentile, 2018). Il est intéressant de noter qu’une activité physique d’intensité moyenne agit également sur le facteur de transcription du Nrf2 (Gomez-Cabrera, 2008). Cette action similaire des polyphénols laisse croire que cela aurait possiblement un effet sur la dépense énergétique totale et sur le profil d’activité physique, mais aucun résultat significatif à ce niveau n’est ressorti avec le projet de ce mémoire.

Avec les bienfaits potentiellement prometteurs des polyphénols, il est de plus intéressant de se pencher vers le potentiel d’autres suppléments. La créatine est l’une des aides ergogéniques les plus populaires chez l'athlète (Kreider, 2017). Au-delà des effets sur la performance sportive, l'apport de créatine peut prévenir ou retarder l'apparition de problèmes de santé, tels que le diabète de type 2, l'obésité et le syndrome métabolique en améliorant la sensibilité à l'insuline (Gualano et al. 2008). Des bénéfices significatifs pour la santé seraient apportés par une consommation de 3 grammes par jour (Kreider, 2017). Cela correspond à environ la moitié de l'apport en créatine d'une diète typique (Brosnan, 2016). La créatine aurait également des propriétés positives dans un environnement obésogène compte tenu de son action sur la prise de masse musculaire et de force (Rawson and Perksy, 2007). Une revue de littérature concernant les effets de six suppléments nutritionnels, censés augmenter la masse maigre et la force, conclut que seules les supplémentations en créatine et en β-hydroxy-β-méthylbutyrate (HMB) se révèlent efficaces (Reents, 2000). L'HMB, un métabolite de la leucine, pourrait donc aussi jouer un rôle en prévention du développement de l'obésité. À ce sujet, deux études randomisées contrôlées ont rapporté une diminution de la masse adipeuse et une tendance à augmenter la masse maigre suite à une prise en HMB (Nissen, 1996; Vuckovich, 1997). La L-carnitine pourrait aussi avoir un rôle potentiel sur des paramètres de la dépense énergétique et de sédentarité compte tenu de son rôle important dans le métabolisme des acides gras. En effet, la présence et la disponibilité en L-carnitine permet aux acides gras de traverser la membrane mitochondriale pour passer du cytosol vers l'intérieur de la mitochondrie, où ils peuvent par la suite y être dégradés lors de la β-oxydation (McGarry, 1997). Certaines approches expérimentales suggèrent que la L-carnitine augmente effectivement les taux d'oxydation des acides gras (Seim, 2002; Wutzke, 2004) alors que d'autres ne relèvent aucun effet (Lien, 2010). La L-carnitine aurait un effet préventif concernant les risques associés avec la prise de masse corporelle et l'obésité, soit les maladies cardiovasculaires (DiNicolantonio,

2013) et le diabète de type 2 (Vidal-Casariego, 2013). Ainsi, il s'avère que la créatine, l'HMB et la l-carnitine sont des suppléments nutritifs pouvant possiblement agir en contexte de surnutrition sur le profil d'activité physique.

Avenues de recherche et limites

L'augmentation de l'ingestion calorique est certes associée à un risque élevé de développer un surpoids et de l'obésité (Rosenheck, 2008), mais d'autres mécanismes déterminant de la prise de masse corporelle semblent entrer en jeu. Le projet du présent mémoire s'est concentré sur l'interaction entre les paramètres de dépense énergétique, de sédentarité et d'activité physique lors d'une diète de surnutrition en présence ou non d'une supplémentation en polyphénols. Il serait également intéressant de vérifier l'effet protecteur d'autres suppléments sur la balance énergétique, tels que la créatine, l'HMB et la L-carnitine en contexte de surnutrition. Toutefois, il sera primordial de standardiser les techniques d'évaluation de ces paramètres afin d'améliorer la reproductibilité des résultats. Les tests en laboratoire s'avèrent souvent incapables de détecter des différences au niveau de certains paramètres d'activité physique. Avec l'arrivée d'outils tels que l'accéléromètre et l'eau doublement marquée, il est possible d'observer l'effet d'une supplémentation dans un contexte de vie réelle. Le défi des prochaines études abordant ces thématiques sera manifestement de séparer et d'identifier l'activité volontaire et non volontaire pour avoir un indice encore plus précis du NEAT. Finalement, une avenue de recherche intéressante serait d'évaluer le comportement différencié existant entre les individus avec obésité et ceux ne présentant pas d'obésité en contexte de surnutrition. Selon Fronseca et al. (2018), il n'a pas encore été possible d'identifier quelle composante de la dépense énergétique contribue le plus à ce comportement différencié (dépense énergétique au repos, dépense énergétique pendant l'activité physique ou thermogenèse alimentaire).

Implication dans le projet

Suite à la détermination du mon projet de recherche, une revue approfondie de la littérature a été complétée dès le début de ma maîtrise. Celle-ci a conduit à la publication d'une revue systématique (Giroux et al. 2018) suivant les directives de PRISMA, ce qui en fait une recension complète et conforme aux exigences d'un tel article. En parallèle, la collecte de données du projet se déroulait en France grâce à une collaboration avec l'équipe de l'Université de Lyon. Les données brutes en accélérométrie ont été recueillies et j'ai ensuite effectué l'analyse statistique et l'interprétation des données, ce qui a mené à l'écriture du deuxième article de ce mémoire avec l'équipe de co-auteurs. Par la suite, une collaboration avec le département de Sports, Exercise and Nutrition à Massey University en Nouvelle-Zélande m'a permis d'effectuer un séjour de recherche où ma responsabilité était de mettre en place un projet portant sur l'accélérométrie. Cela m'a permis de mettre en pratique deux aspects qui n'étaient alors pas abordé lors de mon projet de mémoire, soit la collecte et l'extraction des données. De plus, ce séjour de recherche s'est terminé par le transfert de mes connaissances aux étudiants du baccalauréat de cette Université. En somme, le projet de maitrise a nécessité plusieurs collaborations, ce qui m'a permis de développer des compétences diverses en communication et en résolution de problèmes.

Conclusion

Il est important de réaliser que la prise de masse corporelle menant à l'obésité est la résultante d'une multitude de causes, mais également de certains éléments protecteurs. Parmi ces éléments protecteurs, l'activité physique spontanée et la réduction de la sédentarité sont des éléments qui sont de plus en plus soutenus par la recherche scientifique. Il a été possible d'observer via la présente étude qu'une surnutrition et une supplémentation en polyphénols ont peu d'effets sur les paramètres de sédentarité et d'activité physique dans une population en santé. Toutefois, il y a une tendance de changements au niveau du NEAT qui devra être étudié plus en détails dans le futur. D'autres études sont nécessaires afin de vérifier toutes les composantes du NEAT en contexte de vie réelle, tels que gigoter et maintenir sa posture. Pour conclure, c'est avec l'espoir que ce projet inspire d'autres études de surnutrition, mais aussi de supplémentation et de composition de diète à mesurer un maximum de paramètres du profil d'activité physique.

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Annexe – Risk of bias assessment

	Sequence generation	**Allocation concealment**	**Blinding participants and personnel**	**Blinding outcome assessors**	**Incomplete outcome data**	**Selective outcome**	**Other source of bias**
Apolzan et al. (2014)	High risk	Unclear risk	High risk	High risk	High risk	Low risk	High risk
Bray et al. (2015)	Unclear risk	Unclear risk	High risk	High risk	High risk	Low risk	Low risk
Dirlewanger et al. (2000)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	Unclear risk
He et al. (2012)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	Low risk
Joosen et al. (2005)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	Unclear risk
Klein and Goran (1993)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	High risk
Levine et al. (2008)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	High risk
Levine et al. (1999)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	Low risk
Muller et al. (2015)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	Low risk
Pasquet et al. (1992)	High risk	Unclear risk	High risk	High risk	High risk	Low risk	Unclear risk
Siervo et al. (2008)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	Low risk
Ravussin et al. (1985)	Unclear risk	Unclear risk	High risk	High risk	Low risk	High risk	Low risk
Roberts et al. (1990)	Unclear risk	Unclear risk	High risk	High risk	Low risk	Low risk	High risk
Schmidt et al. (2012)	Unclear risk	Unclear risk	High risk	High risk	Unclear risk	High risk	Low risk
Weyer et al. (2001)	Unclear risk	High risk	High risk	High risk	Low risk	Low risk	Low risk

Study : Apolzan et al. (2014)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	High risk.	Quote : «participants were enrolled from June 2005 through October 2007 on a rolling basis and not in cohorts. »
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	High risk.	Numbers randomized into each intervention group are not clearly reported.
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported.
Other bias		
Other source of bias	High risk.	Exercise is prohibited. Physicial activity related to lifestyle is not considered.

Study : Bray et al. (2015)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	Quote : «participants were enrolled from June 2005 through October 2007»
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	High risk.	Quote : « Participants were randomly assigned to one of 3 different protein diet ». Numbers randomized into each intervention group are not clearly reported
Reporting bias		
Selective reporting	Low risk.	
Other bias		
Other source of bias	Low risk.	Exercise is prohibited.

Study : Schmidt et al. (2012)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Unclear risk.	Numbers randomized into each intervention group are not clearly reported
Reporting bias		
Selective reporting	High risk.	Not all prespecified outcomes were reported
Other bias		
Other source of bias	Low risk.	None

Study : Dirlewanger et al. (2000)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	There is only one intervention including all participants.
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		
Other source of bias	Unclear risk.	No information about physical activity indication.

Study : He et al. (2012)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	Quote : « Thirty-one volunteers were screened for this study form October 2007 to July 2009. Eight subjects were excluded for not meeting the criteria and other reasons »
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	There is only one intervention including all participants.
Reporting bias		
Selective reporting	Low risk	All prespecified outcomes were reported
Other bias		

Other source of bias	Low risk.	Subjects were instructed not to exercice

Study : Joosen et al. (2005)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	There is only one intervention including all participants.
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		
Other source of bias	Unclear risk.	Quote : « subjects maintained their normal lifestyles (work, education, sports participation) throughout the study »

Study : Klein and Goran (1993)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	There is only one intervention including all participants
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		
Other source of bias	High risk.	Quote : « [subjects] were free to move around within the Clinical Research Center during the study and had access to a stationary bicycle ergometer; however,

		physical activity was not directly monitored»

Study : Levine et al. (2008)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	Quote : « Ten subjects (5 women and 5 men) were lean (BMI<25 kg/m^2) and 12 subjects (7 women and 5 men) were obese (BMI> 29 kg/m^2) » Numbers randomized into each intervention group are clearly reported
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		

Other source of bias	High risk.	Quote : « subjects were instructed not to adopt new exercise practives and to continue their usual daily activities and occupation»

Study : Levine et al. (1999)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	Quote : « Sixteen nonobese adults (12 males and 4 females, ranging in age from 25 to 36 years) underwent measures of body composition and energy expenditure » Numbers randomized into each intervention group are clearly reported
Reporting bias		

Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		
Other source of bias	Low risk.	Quote : « Altough we appreciated that volitional exercise might change in response to overeating, we viewed this as a behavioral rather then a physiological adaptation and so elected to eliminate it as a confounding » variable»

Study : Muller et al. 2015		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	Quote : « Study 1 followed the original 6-wk intervention protocol » Numbers randomized into each intervention group are clearly reported

Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		
Other source of bias	Low risk.	Quote : « A physical activity level of 1.4 was taken to resemble a sedentary lifestyle »

Study : Pasquet et al. 1992		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	High risk.	Quote : « Nine lean young adult men volunteered for study throughout the Guru Walla session, having been fully informed of our goals and procedures »
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data	High risk.	Participant included in the analysis are not exactly those who were randomized

addressed		into the trial.
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported.
Other bias		
Other source of bias	Unclear risk.	No information about physical activity indication.

Study : Siervo et al. (2008)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	Quote : « No subjects were excluded from the study for intercurrent adverse events. One subject did not complete the final OF period and ad libitum phase. »

Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported.
Other bias		
Other source of bias	Low risk.	Quote : « The volunteers were instructed to maintain their usual level of physical activity, and, except for the exercise performed in the metabolic chamber, deliberate additional exercise was not allowed ».

Study : Ravussin et al. (1985)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data	Low risk.	Quote : « Sixteen nonobese adults (12 males and 4 females, ranging in age from

addressed		25 to 36 years) underwent measures of body composition and energy expenditure » Numbers randomized into each intervention group are clearly reported
Reporting bias		
Selective reporting	High risk.	Quote : «This preliminary study was used, not onlu to determine each individual's « free-ranging » energy requirements, calculated as Ee within the chamber plus an estimated 25% for physical activity while outside the chamber (unpublished observation » Data not available.
Other bias		
Other source of bias	Low risk.	Quote : 1) « The five subjects were known to have maintained their body weight essentialy constant over 2 yr before the study» 2) « no vigorous physical activity was permitted in the chamber, spontaneous physical activity was estimated by radar »

Study : Roberts et al. (1990)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information
Allocation concealment	Unclear risk.	No information

Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	Quote : «The subjects were 7 young and 9 older men of typical body weight and fat content» Numbers randomized into each intervention group are clearly reported
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported
Other bias		
Other source of bias	High risk.	Quote : « At the time of the study, all were either full-time students, individuals employed in sedentary occupations, or retired».

Study : Weyer et al. (2001)		
Entry	**Authors' judgement**	**Support of judgement**
Selection bias		
Random sequence generation	Unclear risk.	No information

Allocation concealment	Unclear risk.	No information
Performance bias		
Blinding of participants and personnel	High risk.	Open label
Detection bias		
Blinding of outcome assessment	High risk.	Open label
Attrition bias		
Incomplete outcome data addressed	Low risk.	Quote : «Fourteen male subjects, seven Caucasians and seven Pima Indians participated in this study» Numbers randomized into each intervention group are clearly reported.
Reporting bias		
Selective reporting	Low risk.	All prespecified outcomes were reported.
Other bias		
Other source of bias	Low risk.	Quote : « All subjects were abstained from strenuous activity »